General Technical Report RM-55

INTEGRATED INVENTORIES OF RENEWABLE NATURAL RESOURCES: PROCEEDINGS OF THE WORKSHOP

January 8-12, 1978
Tucson, Arizona

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

Abstract

The purpose of the workshop was to promote efficient, objective, and timely inventory systems through integrated inventories; 82 papers were presented in 9 panels covering: information requirements, current techniques, need for integrating inventories, land classification systems, remote sensing, principles for integrating inventories, data processing, information systems, and state of the art.

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January 8-12, 1978
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Sponsored by: Inventory Working Group, Society of American Foresters; School of Renewable Natural Resources, University of Arizona; Forest Service, U.S. Department of Agriculture; Bureau of Land Management, U.S. Department of the Interior; and the Renewable Natural Resources Foundation.

Foreword

The Integrated Inventories of Renewable Natural Resources Workshop was organized and conducted by the Society of American Foresters' Inventory Working Group and the University of Arizona's School of Renewable Natural Resources in cooperation with the USDA Forest Service, USDI Bureau of Land Management and the Renewable Natural Resources Foundation. The intent of the Society of American Foresters' Working Group is to encourage the interchange and dissemination of information for intelligent resource management. This workshop is a continuation of efforts of the working group to conduct informative workshops open to all disciplines.

As our population increases, the demand for our natural resources also increases. It is imperative that we develop efficient, objective methods of accurately determining the amount, condition and extent of the resources we have. In the past, resource managers have generally conducted functionally-oriented, single-purpose inventories. Because of increased concern for the environment, we must gather information on additional resources.

The purpose of the workshop was to promote development of efficient, objective and timely inventory systems through integrated inventories. The keynote address "A Resource Manager's Look at Information Needs" by Andrew L. Bettwy, Arizona State Land Commissioner set the stage for the workshop.

The keynote address was followed by identification of the kinds of information each resource needs to manage that particular resource. Participants then looked at the present procedures for collecting the individual resource data. Next the need for collecting data through an integrated process at various interest levels was examined.

Various land and vegetation classification schemes, remote sensing opportunities, statistical considerations in integrating inventories and the available data processing packages and systems were reviewed. Finally a group of state-of-the-art papers summarized how far we have come in integrating inventories.

The material presented at the workshop, contained in these proceedings, supplements the proceedings of the Inventory Design and Analysis Workshop held in Fort Collins, Colorado in 1974, the Systems Analysis and Forest Resource Management Workshop held in Athens, Georgia in 1975, and the Resource Data Management Symposium held in West Lafayette, Indiana in 1976.

For those of you who could not attend the workshop, the papers in this report will be of substantial interest. Publication of these proceedings was made possible through the allocation of a major portion of the registration fee, and contributions by the USDA Forest Service and the University of Arizona. The USDI Bureau of Land Management published and mailed out the brochures and allowed time for the program chairman to work on the workshop. Success of the workshop must be attributed to the extra efforts of the following people: Pete Ffolliott, John Reinbold, Jim LaBau, Dave Robinson and Wesley Bates. Special thanks to Bob Hamre for editing and assembling these proceedings. Quick publication depended on the cooperation of the authors in preparing their papers in final form, ready for photo-offset reproduction. Lastly, a sincere thanks to the Day Chairmen, Panel Moderators, speakers and all the participants for their individual interest and collective enthusiasm that made the workshop a success.

H. Gyde Lund, Program Chairman

TABLE OF CONTENTS

Page

Foreword i
H. Gyde Lund

Keynote Address: Resource Inventories and Agency Decisions 1
Andrew L. Bettwy

Panel I--Information Requirements for Resource Management:
Moderator's Comments. 4
Charles O. Minor

Toward an Integrated Ecological Assessment of Wildlife Habitat. 5
Harry N. Coulombe

The Opportunity Spectrum Concept and Behavioral Information in Outdoor Recreation Resource Supply Inventories: A Rationale 24
B. L. Driver and P. J. Brown

Data Requirements for Management of Rangelands. 32
Floyd E. Kinsinger

Disintegrated Inventories of Natural Resources. 37
Jack Jacks, Dean Pennington, and Lynn Kantner

Information Requirements for Tember Management: Just Part of an Integrated Information System. 42
Peter R. Russell

Information Requirements for Wildlife Management. 45
L. Jack Lyon

Soil Surveys--the Basis for Management. 53
Douglas S. Pease

Surveys for Forest Resource Demand Analysis 56
Robert N. Stone and Thomas C. Marcin

Ecological Inventory Needs for Mine-Land Reclamation Planning 62
Tika R. Verma, Jon Rodiek, and W. O. Wilen

Information Requirements for Watershed Management 68
Edwin R. Lawson

Panel II--Current Resource Inventory Techniques:
Moderator's Comments 72
Thomas E. Avery

The Opportunity Spectrum Concept and Behavioral Information in Outdoor Recreaction Resource Supply Inventories: Background and Application. . . . 73
P. J. Brown, B. L. Driver, and C. McConnel

Techniques and Principles of Stream Fisheries Surveys. 85
James W. Mullan

Current Rangeland Inventory Methods--Compatibility Toward an Ecological Base?. 91
Richard E. Francis

Page

Inventorying Small Streams and Channels on Wildland Watersheds 104
Robert L. Beschta

A Short Survey of the Worldwide Forest Inventory Methodology 114
Tiberius Cunia

The Techniques and Principles of Soil Surveys on Forest Lands. 121
E. C. Steinbrenner

Current Wildlife Habitat Inventory Techniques and Their Use in Habitat Management. 125
Richard M. Kerr

The National Heritage Trust Program: Information Systems for a National Objective. 131
Susan D. Smith and Paul Pritchard

Panel III--Need for Integrating Inventories:
Moderator's Comments. 134
Hardin R. Glascock, Jr.

National Integrated Inventories--Is What You Need What You Do?. 136
Thomas E. Hamilton

Regional Integrated Resource Inventories--A Place for Coordination. 140
William J. Pulford

Integrating Broad-Based Forest Inventories with Management Inventories for Small Private Ownerships 143
Carlton M. Newton

Integrated Resource Inventories of Industrial Forest Land 147
Louis O. House

Methodologies for Designing Resource Inventories to Support Management Information Systems 150
Dwight R. McCurdy and Charles C. Myers

Panel IV--Land Classification Systems:
Moderator's Comments 155
Richard S. Driscoll

Modified Ecoclass--A Forest Service Method for Classifying Ecosystems. 157
Robert F. Buttery

Land Classification as a Base for Integrated Inventories of Renewable Resources 169
Philip Gimbarzevsky

The USGS Land Use and Land Cover Classification System 178
Richard E. Witmer

The Role of National and International Coordination in Ecological Land Classification 183
Ed B. Wiken

Techniques Developed and Presently Being Used to Conduct the National Wetlands Inventory Project. 192
John H. Montanari and Bill O. Wilen

Page

Shrubland Classification in the Central Rocky Mountains and Colorado Plateau. 199
Scott L. Ellis

Panel V--Role of Remote Sensing:
Moderator's Comments. 204
Robert C. Heller

Remote Sensing in Multi-Stage, Multi-Resource Inventories 205
Philip G. Langley

Potential Applications of Satellite Imagery in Some Types of Natural Resource Inventories 209
Wayne Rohde

Satellites for Practical Natural Resource Mapping? A Forestry Test Case. 219
Emily S. Gryant, Arthur G. Dodge, Jr., and Samuel D. Warren

Mapping Vegetative Cover by Computer-Aided Analysis of Satellite Data 227
Roger M. Hoffer and Michael D. Fleming

An Evaluation of Small-Scale Color Infrared Photography for Integrated Resource Inventories 238
Karl M. Hegg

Vegetation Condition Estimates Using Color Infrared Aerial Photography. 242
Marshall D. Ashley, Daniel Corcoran, and Louis Morin

Application of MSS Systems to Natural Resource Inventories. 248
F. G. Sadowski, W. A. Malila, and R. F. Nalepka

Remote Sensing Streams. 257
Paul Cuplin

Panel VI--Principles for Integrating Inventories of Renewable Resources:
Moderator's Comments 260
Kenneth D. Ware

Objectives of Multi-Resource Inventories in Relation to Design Considerations. 267
W. E. Frayer

Developing Efficient Estimation Techniques for Integrated Inventories. 270
Thomas W. Beers

Specifying Precision in Natural Resource Inventories 276
David A. Hamilton, Jr.

Design of Integrated Natural Resource Surveys. 282
David D. Chapman

Bayesian Theory and Multi-Resource Inventory 291
Alan R. Ek and James N. Issos

Time-Space and the Inventory of Ecosystems 299
Richard J. Alvis

Page

Potential of 3P Sampling in Wildlife and Range Management. 304
Harry V. Wiant, Jr. and Edwin D. Michael

A Framework for Allocating Inventory Resources for Multiple-Use Planning 307
R. Dean Stuck and Harold E. Burkhart

Metrication: Its Application in Forest Mensuration. 315
David W. Robinson

Panel VII--Data Processing Systems:
Moderator's Comments. 317
John W. Moser, Jr.

An Automatic Data Processing System for Multiple Resource Inventories 319
Dieter R. Pelz

Using Short Programs in Natural Resource Inventories. 325
James P. Barrett and David S. Linden

Error Processing Systems for Integrated Resource Data 328
William O. Rasmussen and Peter F. Ffolliott

FINSYS--A Tool for the Processing of Integrated Resource Inventory Data 332
Joseph E. Barnard

Data Processing Systems for Small Ownerships. 336
James C. Space

Timely Resource Information Through Process Modeling: The North Central System Experience. 344
Roland G. Buchman

Panel VIII--Natural Resource Information Systems: Their Role in Today's Decision Environment:
Moderator's Comments 350
B. Bruce Bare

Computer Mapping Systems for Integrated Resource Inventories 354
Elliot L. Amidon

Timber-Pak--A Second Generation Forest Management Information System 360
Jan W. van Roessel, Philip G. Langley, and Terrell D. Smith

Computer-Assisted Resource Management. 375
Larry E. Beeman

Resource Management Systems--The Cost. 382
D. R. Johnston

ECOSYM: A Classification and Information System for Wildland Resource Management. 384
J. A. Henderson and L. S. Davis

Integration of Data Information Between Agencies 390
R. Eugene Wunderlich

Page

Panel IX--State of the Art:
Moderator's Comments 392
Vernon J. LaBau

A Multifunctional Inventory Approach to Multiple Use Analysis. 395
Peter F. Ffolliott

Reconnaissance Biophysical Soil Inventories in British Columbia:
A Case Study of the Northeast Coal Area 403
Terje Vold

Integrated Inventories in the Tennessee Valley Region 412
Robert P. Gregory

Multi-Resource Inventories in Mexico 420
Miguel Caballero

Multi-Resource Inventories: A Potential of the Forest Survey. 425
Harold E. Grelen and Clifford E. Lewis

Multi-Resource Inventory in the Philippines. 430
Severo R. Saplaco

BLM Intensive Inventory Classification System. 434
Gerald L. Nilles

Decay Amount and Distribution--Some Estimating Methods 440
Donald D. Munro

A Practical Approach to Biological Inventories for Ecological
Baseline Studies. 447
James B. States

Integrated Multi-Resource "In-Place" Inventories 454
Norman S. Adams

A Comprehensive Inventory System for Forest Resource Management. 463
Gerald A. Rose

Current and Future Biomass and Resource Inventory Techniques 469
Harold E. Young, Theodore C. Tryon, and Clifford L. Swenson

A National Multiresource Inventory System: Possibilities, Problems,
and Progress. 474
Robert C. Aldrich

Workshop Wrap-Up 481
H. Gyde Lund

Keynote Address:

Resource Inventories and Agency Decisions[1]

Andrew L. Bettwy[2]

Abstract.--Talk would place land management agency within its perspective: policy, responsibility. Further development of this perspective includes the scientific community, organized to create a system of resource inventory methods which would be of best service to the administrator of a land agency. Talk raises question: what adjustment to existing resource inventory system would make the inventory more useful. Talk responds to that question with proposed adjustments.

I am honored to have been asked to commence your proceedings and do so from the point of view of a prototype land agency administrator. It is a job of mixed emotions, frustrations for many reasons, and gratifications when the work occasionally does some identifiable good for society. The word society best fits my thinking as the beneficiary of our successes rather than the term "public" because it is my conclusion that it is society that ultimately absorbs the impact of our work -- yours and mine.

I suggest for our thinking today, that the resource scientist, the resource agencies and their administrators are engaged in the most basic kind of social work: maintaining the support systems of life itself while committing these systems to the dynamics that produce the food, fibre and shelter of humanity. I find this an exciting thought . . . one which should put each of you, with your special talents and gifts "on your mettle" . . . fill you with a sense of constructive anxiety . . . a kind of starting-line psychology, where you perceive the empirical needs of the people and see the opportunity to serve these needs with your particular skills and your personal grasp of that simple but stunning equation: the oneness of man and creature and earth.

Society organizes its needs through its "public". In our work, we are well acquainted with the face of this public when the needs involve the application of natural resources . . . land, air, water, wildlife or space. The public method is activistic and its resolution is always political or legal, or both. The public face is a sectionalized one: commodity interests, environmental interests and the cultural-economic interests of native Americans . . . the Indians and Eskimos of the lower forty-eight states. It is this public force of society that precipitates the laws, rules and regulations of resource administration. These laws and regulations, along with some key court rulings, create the policies under which land agencies, federal or state, operate. These policies may also influence the outcome of your own research, as resource inventories are reported to an agency and become part of the agency's decision system. This observation is made as a recognition of policy as a point of departure from which we can explore new reaches of its interpretation.

We might quickly mention a cluster of federal laws which are currently influencing the management policies of the US Forest Service, the Bureau of Land Management, the Department of Energy . . . and, for that matter, affecting policy at the level of the management of state lands, particularly in the west.

Such a summary would have to include the report and recommendations of the Public Land

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[1]Paper presented at the Integrated Inventories of Renewable Natural Resources, A National Workshop, Tucson, Arizona, Jan. 8 - 12, 1978.

[2] Arizona State Land Commissioner, State Land Department, Phoenix.

Law Review Commission, a federal, executive commission that operated from 1964 through 1970. Its work was the first real scrutiny of the ownership and use of common lands since the Hoover Commission. The final report of the Land Law Review Commission revived congressional and public interest in public lands with an intensity not previously known. The modernization of federal management agencies is still taking place and the recent passage of organic legislation for the Bureau of Land Management is a tangible result of the work of this commission.

The Wilderness Act of 1964, a pattern preservationist law that brought with it a train of others such as the Wild and Scenic River Act, the Eastern Wilderness Act, the National Trails System Act, and others.

The Environmental Policy Act (NEPA), legislation which personalized the environment. It gave the individual citizen the right to sue in court on questions related to public land use. It has legislated in areas that concern the air you breath, the water you use, and harmful toxins. It is my recollection that Act was adopted unanimously by Congress.

The Federal Land Management & Policy Act of 1976: it should be noted that this is essentially a land retention act, including its mandate for wilderness and roadless area designations.

The Renewable Resources Act of 1976: the US Forest Service, essentially an inventory legislation, with strong emphasis on environmental values.

The Surface Mining Control and Reclamation Act of 1977 (strip mining) legislation. It regulates and standardizes land restoration.

These laws give us a fairly typical composite of the public thrust toward appraisal of total environmental values. A definition of environment is deserving at this point; "the complex of climatic edaphic, and biotic factors that act upon an organism or an ecological community and ultimately determine its form and survival; the aggregate of social and cultural conditions that influence the life of an individual or community".[1] More than a thrust, environment is established and is a national ethic. It should be when that definition is kept in mind.

[1] Webster's Seventh New Collegiate Dictionary. Based on Webster's Third New International Dictionary. Copyright 1967 by G & C Merriam Co.

The interrelationship of the laws we have mentioned is obvious. All carry sections which would infer challenge to the traditional functional uses of the land. All have been passed within the span of a dozen years. It seems that resource legislation of a purely economic quality has grown inversely over this same span of twelve years. As it should be, the pulls in different directions are in constant flow -- the pendulum has been used to describe the action.

Resource agencies now more than ever before operate their policies somewhere within the apparent dichotomy of life-support systems (the environment) and life-giving systems (the economy). I say apparent, because in the broad sense both systems are part of the environment and what we seek is a harmonious activity which considers and provides for all values. The decision system of a resource agency is responsible to the public, the executive and the congress. Not all agency decisions are high-profile, public issues, but for purposes of display, this morning, I shall choose a land issue that is now impending on the Forest Service, the Bureau of Land Management, National Parks and the Refuge System throughout the west: this is the ISSUE OF ROADLESS AREAS, and its influence reaches beyond the federal level. It affects the management policies of western state-owned lands as they are interspersed among federal land.

The ROADLESS AREA INVENTORY is an active program of the US Forest Service, and it is referred to as RARE II.

As you know, a "roadless area", in the context of the law, is any area of 5,000 acres minimum which is not now classified as primitive or wilderness, but which would appear on examination to qualify as wilderness because of certain undisturbed, untrammeled or "pure" natural characteristics it may exhibit. A roadless area becomes a candidate wilderness area once its qualifications have been verified by agency site studies and a wilderness classification has been recommended to Congress by the agency through the Office of the President.

In Arizona in late September, 400,000 acres for roadless evaluation were submitted to the Forest Service. The site list was the result of a persistent five-year, statewide field survey largely conducted by volunteers concerned with environmental values they believe have been overlooked. The Forest Service is digesting this list, purging some areas and adding areas on its own. Area by area it is the object of hot public debate. Thousands of acres of ranch land are involved in these proposals and third parties to the dialogue between the activist groups and the United States Government -- the mining, the wildlife preserves and other traditional users

are making their input. The decisions that have been made and that will be made are monumental. At the base of the right decision is resource inventory.

It looks like the Roadless Area program is almost self-organized to receive the overlay of an innovative resource inventory process. So, may I propose that we accept it as a framework on which to hang our speculations this morning.

I must assume that your use of the word "integrated" is in a concept broader than your standard interdisciplinary format. You appear to be searching for methods that will give your facts . . . or truth . . . a mix which can be applied in every area of the issue: biotic, edaphic, economic, yes, even political. If I am correct in this assumption, then the resource agencies and the public are in luck . . . because joining the scientific community is imperative if decisions are to be made on fact. Placed at the receiving end of a resource inventory, a land agency would welcome these values as primary:

1. physical and measurable data on the natural systems, economic facts and demogenic facts of the region or immediate area;

2. conclusions -- by conclusions I mean this same body of facts after it has been washed through a process of multiple discussions at every level of its development, from field to town hall.

Data and conclusions can be mutually supportive if they are handled with equal care. Working together, they can be the dynamic that produces "integration" in resource inventory systems. You can sense that the development of field inventory on such an information scale would call for a recasting of the inventory team itself: the interdisciplinary arrangement of scientists would remain, but new disciplines would seem necessary to be locked into the inventory structure -- and at the practical level must be included laymen and area residents who are qualified to articulate the progress and impact of the study to their communities.

This would be a bold and chancy way to develop and utilize a resource inventory program. Viable options, fresh alternatives, new time thresholds of environment or economics will surface in this process of experiment. And, we might produce environmental impact statements born free of static language, reports that would be alive and kicking because they were written from the lexicon of all fact and aspiration involved.

The challenge to you, to people like me, as resource managers is as broad as we are willing to envision and accept. The results will be not better than the information and system for its use that we develop. The process has no end.

Panel I — Information Requirements for Resource Management: Moderator's Comments[1]

Charles O. Minor[2]

This panel has the very necessary task of establishing the information needed for management of the multitude of resources and resulting problems facing the modern land manager. Before an inventory is designed and conducted we must determine information needs and objectives. Prior analysis and planning might do away with some of the "since we're on the ground we might as well measure it-syndrome!"

Good morning. We are about to start what should be a most useful and therefore successful workshop.

I wish to add my welcome to Arizona. Being completely spoiled, I am now on my twentieth year in Arizona and not about to leave. I am sorry you-all will only be here part of a week--also that you will not be able to visit the northern and timbered part of our state.

Our purpose in this first panel is to establish the information requirements for the many resources with which the modern land manager must cope. Certainly successful and continuing management of natural resources requires large amounts of varied and usable data. These requirements change over time. In early stages of management we need basic stock-taking information; later as management intensifies, our data needs shift to production or continuing inventories.

[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan. 8-12, 1978.

[2]Dean, School of Forestry, Northern Arizona University, Flagstaff, Arizona.

So, we'll look at information needs for help in inventory design. This seems an obvious first step, an obvious requirement of every inventory regardless of complexity. But all too often the obvious is ignored as we go rushing to the field to collect data. Inventory planning always requires assessing the available and required information and determining objectives. The multiple-resource or integrated inventory requires these same steps, it is just that now we may have several items of information, each may have different utility and require different levels of precision. Each item may have one to several constraints. The sampling intensity may vary widely between resources--we may use more than one type of sample. Thus again we see the importance of specifying the information needs of every inventory.

So, in the papers to follow we're going to look at a number of resource areas (wildlife, recreation, range, minerals, timber, soil, water) as to information requirements. Perhaps by the time each specialist outlines the needs for his resource area you will conclude that the situation is hopeless-that we'll never be able to design a truly integrated inventory. Fortunately, I guess I am more optimistic. At any rate, let's plunge into the first topic and see what develops.

Toward an Integrated Ecological Assessment of Wildlife Habitat[1]

Harry N. Coulombe[2]

Abstract.--An analysis of contemporary conceptual aspects of applied ecology and the decision-related information requirements suggests a model for the logical processes of natural resources assessment. The components of this model are defined and related to resolution considerations. Current FWS programs pursuing these components are described.

INTRODUCTION

The effective incorporation of ecological information and considerations into the natural resource decision-making process has been a clear objective of our professional community for decades. Challenges in the theory and practice of integrated renewable resource inventory and analysis have concerned resource managers throughout this period. The current decade in our nation's history has brought the highest level of public awareness of this need the world has ever experienced. The response of the legislative and judicial branches of our government at all levels has been to mandate that increasing amount of this type of information to be used throughout the scope of our activities. The National Environmental Policy Act of 1969 was a landmark. The Renewable Resources Planning Act of 1974 (RPA) brought a major focus of the national concern for an integrated framework within which to assess the status of our nation's renewable resources. The RPA mandated that quantitative, ecologically oriented, information bases be used to develop long-range programs for the U. S. Forest Service. The National Forest Management Act gave further direction to this assignment. Last year the Bureau of Land Management was similarly directed by Congress through its "organic act." The most recent mandate in a similar vein is the Soil Conservation Service's Soil and Water Resources Conservation Act.

Background

Federal conservation and management agencies find themselves traveling a familiar (but not well-worn) path, urged on by a new set of legal requirements. In 1974 the U. S. Fish and Wildlife Service (FWS) established a major new effort--the Biological Services Program (BSP). The new BSP focused on the development of methodologies and information to provide more effective and timely information on the ecological aspects of fish and wildlife resources and their habitats to its clientele. n 1976 the Habitat Analysis Project was established within the Systems and Inventory division of BSP, and the National Habitat Assessment Group (NHAG) was established as the functional arm of the project. A major charge of NHAG was to work with the U. S. Forest Service, the Bureau of Land Management, the National Park Service, and other federal agencies in developing strategies and methodologies for the ecological assessment of fish and wildlife habitat. Another major charge of this group was to provide an ecologically-based framework for a wide variety of ongoing activities and projects within the FWS related to habitat assessment. The efforts of the BSP were focused on ecological information related to the potential impacts of developing major energy products. A major source of funding was "pass through" dollars from the Environmental Protection Agency. The specific task was to develop timely and effective methodologies for the quantitative consideration of ecological information, focused on wildlife and their habitats, in decision processes.

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[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.

[2]Leader, National Habitat Assessment Group, U. S. Fish and Wildlife Service, Fort Collins, Colorado 80521.

The Nature of the Problem

As the Biological Services Program developed, we recognized the need to clarify the role of ecological information in a decision-process context. Ecologically-based predictions that identified opportunities, constraints, and risks were the focus. These predictions join similar predictions based on technological assessment, and socio-economic and political information as inputs to the decision-maker. Figure 1 portrays a generalized, conceptual model of the relationship of ecological predictions to resource use in the management decision process. The fundamental premises of this generalized scheme are drawn from Eugene Odum's recent discussion of the relationship of holism and reductionism in contemporary ecological endeavor and the need to integrate the science of ecology with other aspects of the social-decision process (Odum 1977). Risks from an ecological perspective should be considered in the array of political, socio-economic and environmental problems (Comar 1977). By the same process, ecological prediction in this context might clarify potential constraints and opportunities. This arena of consideration is, of course, the basis for our current decision processes for resource use and management at all levels of government.

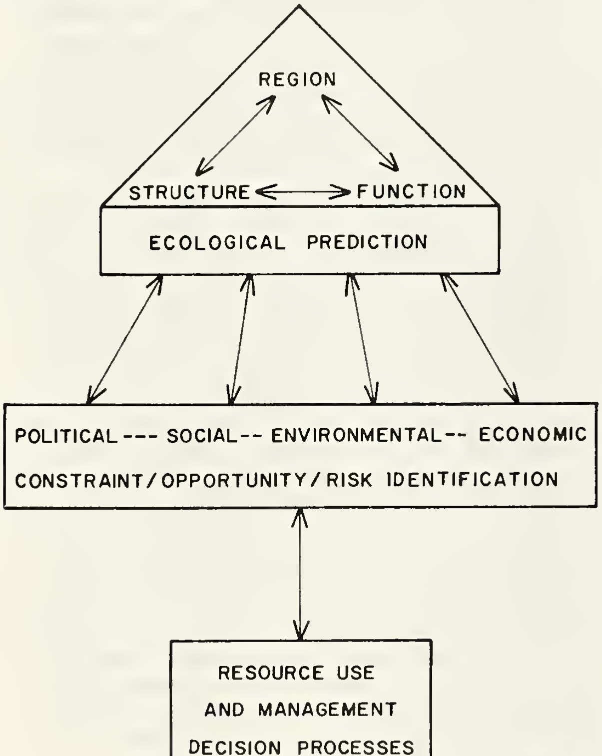


Figure 1.--A generalized conceptual model of the relation of ecological predictions to resource decisions.

The fundamental ingredients required for constructing ecological predictions in this context is the current body of ecological theory and knowledge: the integration of structure and function within defined ecological systems. A fundamental tenet of this synthesis is that the structures of ecological systems (components) interact through functional processes. This synthesis occurs in a conceptual context that is essentially site independent. The integration of ecosystem structure and function on a temporal and spatial basis is the regionalism aspect described by Odum (1977). Odum considers that the regionalism concept, which is well developed in social and economic systems understanding, is a primary focal point for the deliberation of all concerns in societal decision processes.

APPROACH TO THE PROBLEM

Focus of the Assessment Process

An overriding objective of the development of an ecological assessment process is to provide timely, effective inputs to the decision-making process. A number of studies were conducted by BSP to analyze this process within federal agencies, focusing especially on the kind of information used, its format and resolution, at different levels within the bureaucratic hierarchy. Although the Biological Services Program emphasized processes relating to energy extraction and processing, it has also examined decision processes for planning resource management programs. We have developed an operating objective of determining at what point within a complex decision train it is most appropriate to inject ecologically based wildlife information into the processes of the agencies served as clients.

Table 1 portrays a brief overview of the current relationship of wildlife information in the federal government's decision process. The decision levels and the decision classes portrayed in Table 1 represent a true hierarchical disaggregation. The decision information corresponding to these hierarchical levels represents what is perceived to be the principle kind of information used at each level, and is nothing more than a stratification[3]. The kinds of decision information portrayed here refer to actions that present wildlife information as one component of ecological information.

[3]Palmer A. M. 1977. A report on the wildlife and fish habitat parameter workshop, June 13-16, 1977, Pingree Park, Colorado. Cooperative Aid Agreement 16-685-CA, Colorado State University and Rocky Mtn. Forest and Range Exp. Stn. USDA-FS. 41 pp.

Table 1.--A synopsis of the current decision process involving wildlife information in the federal government.

Decision information	Decision levels	Decision classes: types
Species presence/ absence	Congress/O.M.B.	Policies: alternatives programs
Species relative abundance	Agencies	Programs: regional allocation of projects
Habitat quality/ quantity	Regional divisions	Projects: site allocation of projects
Habitat management potential	Resource-management units	Practices: implementation plans of projects

For example, deciding between alternatives for programs are the types of decisions made at the Congressional level. A general class of information used may be the presence or absence of particular species. The presence of an endangered species may be the basis for deleting one or more alternatives at that level.

Once a program has been authorized, an agency then faces a type of decision that may determine a regional allocation of projects to accomplish the program objectives. If a program is aimed at wildlife enhancement through management, the particular species or groups of species of interest usually guide the regional allocation of projects through a knowledge of the projects' effects on the relative abundance of the species in question. Conversely, a program that may have adverse impacts on particular groups or species of wildlife will be regionally allocated to areas of minimal relative abundance of the species of concern.

At the regional division of agencies, a major class of decisions is the actual site allocation of projects. At this level of resolution a major class of information used is the quality and quantity of habitat for the species in question.

At the field level of resource management agencies, the classes of decisions generally can be described as alternatives for practices--the actual implementation plans for a particular project. The type of information used at this level is related to the management potential of habitat units selected for the project. This is a diagnostic process that identifies the particular components of a landscape having the potential for being manipulated to achieve the objectives of the project. The particular combination of manipulation methods that will optimize the objectives of the project and minimize constraints to other management practices or considerations on the site is the decision reached.

Conceptual Considerations

Inspection of the above synopsis reveals some specific problems or questions. First, this description of the current decision process was designed primarily to describe the process used by the U. S. Forest Service in wildlife management decisions, in an attempt to relate the National Assessment (RPA) and Program Development process to different levels of managerial needs[3]. Second, it also indicates that only a portion of the potential topics of ecological assessment may be important focal points. In order to effectively develop a logical process geared toward an integrated ecological assessment of wildlife habitat and ecological relationships, it is necessary to discuss the relationship of these considerations to a unit of consideration.

[3] Ibid.

Perhaps the single foremost concept in contemporary ecology is that of the ecosystem level of organization. The National Academy of Sciences in 1967 defined an ecosystem as "the total system of living and non-living components interacting in a given region of space and time." I believe that resource-management professionals agree the ecosystem concept is the appropriate framework to evaluate competing uses of renewable resources (VanDyne 1969). Some might argue that the ecosystem concept is no more than a concept and has no direct application in the real world management decisions. Thus the basic problem might be stated as the practical application of the ecosystem concept to our resource-management decision-making (Holling 1977).

The solution to this problem is both complex and unclear. One can simply state that the solution lies in the integration of ecological structure and function into an operationally defined region of space and time. However, implementing that integration and synthesis in a real- world mode has not occurred. Major efforts within our scientific community have been brought to bear on this problem, such as the Analysis of Ecosystems Program within the International Biological Program. I think we have learned that the conceptual integration of structure and function within an ecological system is possible. The certainty within which we can predict the status of a system is open to question. I think we also discovered that applying that conceptual understanding of the interactions of components and processes to a specified region of space and time in the real world is a monumental task. A re-statement of the status of "ecosystem studies" into a working paradigm has provided new guidance for the application of ecological principles to the problems at hand (Johnson 1977).

One approach to the problem is to seek an alternative to the frontal assault on the integration of ecological structure, function, and region. An alternative strategy then becomes the use of species assessments as indicators of specifiable attributes of ecosystem structure and function. Most of the methodologies and information presently available to us are focused on species information.

The classical concept of levels of biological organization or integration are portrayed in the left half of Figure 2. The hierarchy of organization from the biosphere to organ systems and below has its basis on functional-process relationships; specifically, the degree of interchange of material and energy between levels of organization. Several of the levels within this hierarchy are difficult to isolate and measure. This is particularly true of levels of organization above the organism. Integrating these levels of functional organization of ecosystems with structural considerations may be addressed through the species requirement philosophy. One can subdivide the concept of habitat for a given species into life requisites (for a review of habitat terminology and concepts see Coulombe, in press). The principal for stratifying by life requirements for animal species is based on ecological theory about the mechanisms of habitat selection. Habitat selection is universally manifested in measurable terms through biogeographic patterns, and through demonstrated preference for zones in environmental gradients. The measurable attributes (habitat preference or suitability) can be derived from data elements of surface cover, soil, land form, and climate. If these major segments of the environment are related to life requirements of the species, they can be termed "habitat components." By definition and convention, the description of the habitat for a given species is equal to the totality of habitat components (Fig. 2).

The spatial extent and, to some degree, the temporal dimensions of the habitat for a species can be ascertained and quantified. The process of summing the habitat components for a variety of species within some defined geographic boundary produces what we might call "multiple-species landscape units," which can be designated "habitat units." The same logical process may be applied to plants, although the particular terminology given in Figure 2 (translating data elements into habitat components) is not precisely tuned to that application. The concept of "habitat unit" presented here seems directly equivalent to the concept of "habitat type" as defined by Daubenmire (1968).

On either side of our representation of structure and function (Fig. 2) we can find a level of classification that has commonly been displayed in map form. Communities, especially of plants, have been designated on maps. Habitat types and the habitat units have been portrayed on maps. Some ecologists consider the concepts of habitat type or biotope, and habitat unit to be spatially equivalent to the map unit representing a potential community or association. This may be a suitable working hypothesis, which can be difficult to test. Current communities or associations are related to contemporary and near-future wildlife use, rather than the site-potential description. Long term considerations for wildlife use must consider both the current status of the plant communi-

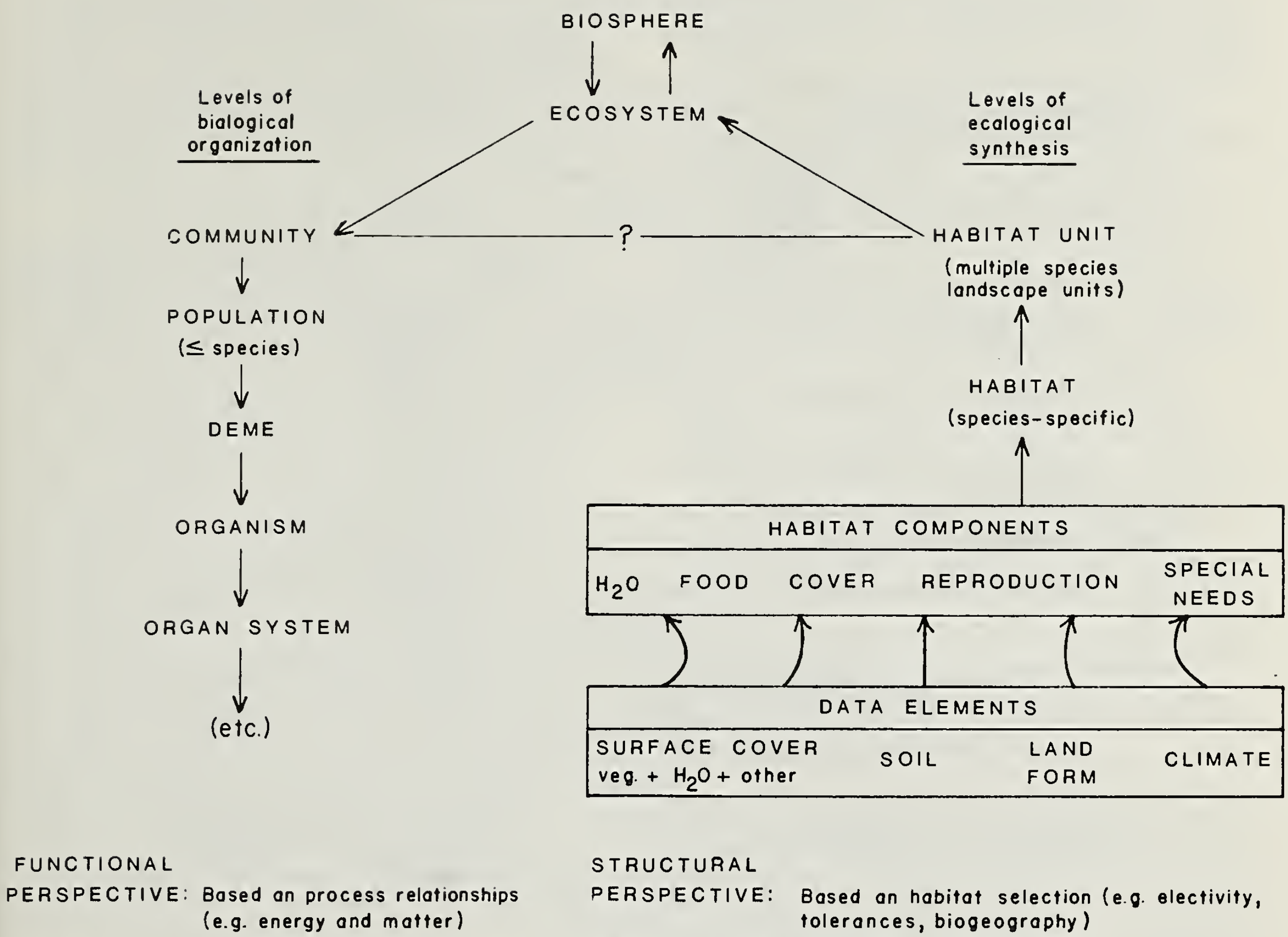


Figure 2.--Integration between structural and functional perspectives of ecosystems.

ties and their direction and rate of change. The next level of integration from either a functional or structural perspective is that of the ecosystem.

Data Requirement Consideration

At this point in the development of an approach to the ecological assessment problem, it is useful to consider the detail of data, their predictive potential, and some indication of the relative cost for collecting data on a land-unit basis (Table 2). The decision information used at the highest level of federal decision making is the resolution of species presence or absence (refer to Table 1). The actual determination of species presence or absence on a given land unit requires ground-based information, such as direct observations of the species in recent times or other information of an indirect nature.

One can infer the potential presence or absence of a species based on historical-distribution records. This inference can be approached by factors such as relation of the presence or absence of habitat units, based on information such as surface cover types present or factors related to some ecological region (a biogeographic-region and/or a physical-component approach). At the next lower level of resolution, the potential presence or absence of a species may be further refined in terms of predicting the suitability of a habitat unit. Further analyses of remote-sensing types of information such as configuration, juxtaposition, or interspersion of habitat units can further refine our prediction of the probability that a given land unit can support the species in question within a specified range of certainty.

A number of complex factors may influence the actual presence or absence of a given

Table 2.--Relations between data requirements, predictive potential, and relative cost for wildlife considerations

Data requirements, in resolution sequence (low to high		Predictive potential: Habitat attributes[1]	Predictive potential: Ecosystem attributes[2]	Relative cost/land unit
Remote-sensing information				
Surface cover type; Ecological region	physical and/or biogeographic	presence/absence of habitat units	predict outputs limits: $X_{min} \rightarrow X_{max}$	$
Configuration (size and shape of unit)		potential habitat unit suitability	predict outputs: $\bar{X} \pm a \cdot \sigma$	$$
Juxtaposition (nearest neighbor)				$$$
Interspersion (degree of homogeneity)				
Ground-based information				
Species presence/absence		amount of occupied habitat units	predict outputs: $\bar{X} \pm \sigma$	$$$$
Species population levels; Species population variation		actual habitat suitability (standing crop)		$$$$$
Species influx/outflux rates; Species life tables; Deme population parameters		potential habitat capability (carrying capacity)	predict outputs: $\bar{X} \pm \frac{\sigma}{a}$	($$$$$)^n

[1]Habitat attributes are elements in the capability of the landscape area to provide the life requisites for a single species or a group of species (guild, life form, class, association).

[2]Ecosystem attributes include interactions between species (such as rate/direction of succession or changes in trophic structure) or systems properties such as net primary production, nutrient pool size or nutrient turnover rates. X represents the value of an attribute; $\bar{X} \pm a \cdot \sigma$ represents the mean value of that attribute with a large confidence interval, whereas $\bar{X} \pm \frac{\sigma}{a}$ represents a small confidence interval for the attribute.

species on any land unit. Other factors influence our ability to analyze species abundance and distribution. Sampling problems are one such factor. The subtle, difficult-to-quantify factors such as behavioral interactions between or among species may influence the probability of detecting a species by any of our currently used sampling methods for wildlife.

Species relative abundance, as determined by population mean level and its variation, is the "ground-truth" for an assessment of actual habitat suitability. In many cases we can infer factors related to the relative abundance of the species from characteristics of the environment that are more economical to measure than is the direct measurement of population levels and their variation through time. The objective is to determine the

current standing-crop biomass or numbers of a species and some description of the dynamics of these parameters. From a habitat-attribute approach, various components of the ecological structure of a habitat unit may be measured such as canopy closure, condition of prey species, and other factors relating to the life requisites of the species in question.

The local unit resource manager is generally concerned with the biological potential of a habitat unit. His concern is relating the wildlife populations presently supported by the unit to the concept of carrying capacity or peak productivity. In some cases, defining the capability of the habitat unit will suggest that the abundance of a particular species is in excess of the long-term, sustained-yield capacity of the unit. In other cases, the determination of habitat capability reveals a management potential for increasing the productivity or standing-crop of a species. Again, we normally diagnose various components of the habitat requirements for the species in terms of directly observable aspects of the landscape such as vegetative cover attributes, land form, evidence of human intrusion and other such landscape features. In the context of population dynamics, the "ground-truth" for the inference of habitat capability are the components of population dynamics such as immigration and emigration rates, natality and mortality rates, and the age-class structure of the population under consideration. For higher levels of resolution information about the local population unit (deme) may be required.

As we look at the ecosystem attributes related to these levels of resolution, we find ourselves with little applied theory to guide development of predictions. However, at the level corresponding to the presence or absence of habitat units, we might only specify the limits of a parameter such as net primary production. Conversely, as we descend the columns in Table 2 to higher levels of resolution, we certainly can reduce the size of the confidence interval around some estimate of a system attribute. A similar logic applies to the level of certainty in specifying a probability of additions or subtractions to the trophic structure of some landscape unit, and to predictions of the direction of succession as another class of ecosystem attributes.

Resolution Considerations

An obvious conclusion to all resource managers is that as one specifies requirements for high resolution in terms of the information required for a decision, the relative cost for a given land unit increases rapidly (Table 2). There are those among us who suggest that regional and national assessments of wildlife (or any other renewable resource) can be built by an aggregative process, based on high-resolution information for landscape units. Clearly this is not feasible within our long-range time frame, even in the next few decades, because it would require enormous resources. One also questions the utility of such an effort because of the rates at which many ecosystem properties change (Holling 1977). Conversely, an approach to the problem that proceeds from general to specific in a divisive manner cannot be expected to supply the level of detailed information required at the ground unit level. It is easy to state that the logical solution to this dilemma is to develop an approach that utilizes a combination of both aggregative and divisive approaches. It is, however, difficult to specify exactly <u>which</u> attributes of either approach to the problem will provide a successful combination. The balance between the "top down" and "bottom up" approaches to the problem becomes more definable as one develops a working model of the logical process for ecological assessment, and then delineates the requirements for each component.

The kinds of ecological assessments of the present and future differ widely in types of data available to them, constraints of time and resources, type of outputs desired, and objectives pursued. Although almost any combination of alternative traits is possible, certain patterns seem to recur. In Table 3, I have tried to bring these patterns into focus by organizing them around classes of methodologies. There are all types of intermediates and combinations however, the classes recognized generally describe the dominant traits of assessments to occur in the near future. In the following discussion a "site" conveys a particular landscape unit that may be less than a square mile to several thousand square miles; a "region" in this context is some larger subdivision of the United States, on the general order of magnitude of several hundred thousand square miles.

Why are ecosystem results not considered at the "site" level of impact analyses? Many of us recognize the importance of such considerations (Odum and Cooley in press). There are two major problems in trying to incorporate functional ecosystem attributes in the assessment process. First, there is only a sparse data base available. At only a very few geographic sites has ecosystem function been examined. The chances of finding a well-studied area within the small

Table 3.--The Purposes, Data Bases, and Results Produced by Four Classes of Methodologies for Ecological Assessments.

	Class of Methodology			
Characteristic	Regional-Ecosystem	Regional-Species	Site-Species	Intensive Site
Purpose	Impact Assessment and Planning			Research & Management
WRC Level*	A & B	A & B	C	None
Size of Area (acres)	> 1,000,000		< 1,000,000 Avg. 35,000	
Remote Sensing Data Base				
Cover type classification complexity	low to medium		medium	high
Classification accuracy	low to medium		high	high
Spatial Resolution	6 to 100 acres		1-2 acres	¼-1 acre
Field Data Base				
New Data Required	little		some	much
Sampling Period (usual)	less than one season			many seasons & many years
Area Sampled (% total)	.1%		1-10%	25-50%
Number of Data Categories/Sample	10 to 20		10 to 20	20
Cursory Survey of Whole Area for Special Features	No		for some	for many
Results				
Subject of outputs	Ecosystem Structure & Function	Featured or Indicator Species		Ecosystem or Species
Detail (resolution)	Low	Low	Medium	High
Certainty (accuracy and precision)	Low	Low	Medium	High
Examples	Indices of vegetation complexity, species diversity naturalness, productivity, etc.	Habitat quality, good vs. poor, for 5 species or guilds	Habitat quality, scale of 1-10, for 10 species	Actual Population Density, productivity etc. for many species

*Water Resources Council, Principles and Standards planning levels.

geographical limits of a project site are quite low. Hence, extrapolations to conditions at the project location are apt to be imprecise and inaccurate. The second problem is that collecting the data necessary for quantifying most ecosystem functional attributes is so costly and time consuming that it is impractical to do so for the immediate future. If the state-of-the-art and constraints of the time and money are sufficiently improved by the time we have dealt with the other three impact assessment methodologies, then we can give this approach the attention it deserves.

A Logical Process for Assessment

The assessment process is composed of at least four component processes: classification, inventory, characterization, and analysis. These component processes are linked together through what I will term "information management systems." The assessment outputs are ecological opportunities, constraints, and the prediction of risks. A diagrammatic model is useful to show a strategic approach to the organization and coordination of efforts to produce the outputs. Figure 3 demonstrates the major logical flow between

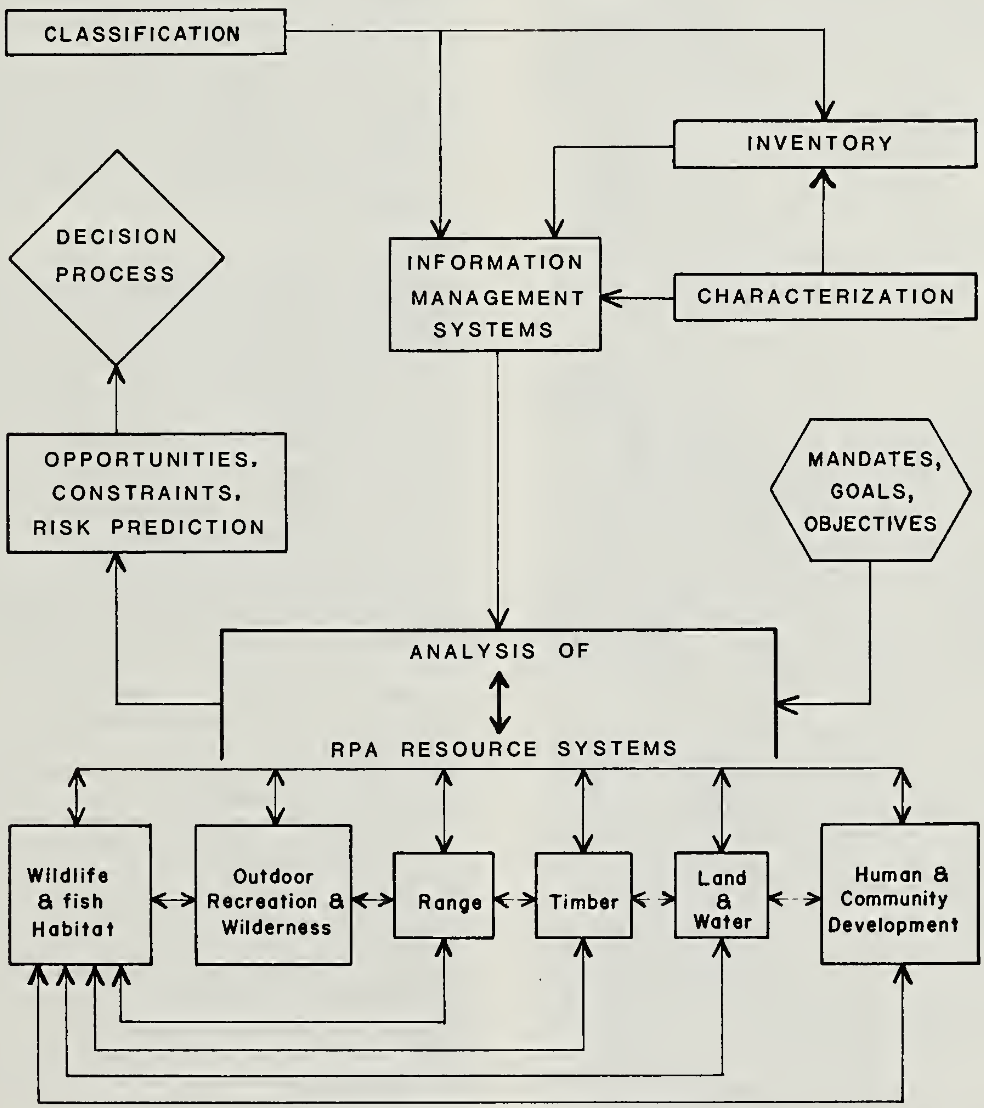


Figure 3.--Logical process diagram for the assessment of renewable resource systems, developed for wildlife and fish habitat resource system component for the Forest and Rangeland Renewable Resources Planning Act of 1974.

the processes of assessment and indicates the relation of this process for the Resources Planning Act (RPA) resource systems. This framework emphasizes the requirement for analytical procedures to be able to interact between considerations for each of the six resource systems. The logical process diagrammed here was developed with particular reference to the national assessment process for wildlife and fish habitat[3].

Approaching the subsequent structuring and prioritizing of future activities, it is useful to take a "top down" approach, which flows in an opposite direction to the inputs into the various components of assessment. Thus the needs of the decision component should be addressed first, as these determine the nature of the inputs to the decision process (Holling 1977). The "analysis" processes identified in Figure 3 are thus clearly driven by Congressional mandates, organizational policy and clearly stated goals and objectives. The absence of clearly defined goals and objectives for the future of fish and wildlife resources is certainly a common problem. This is abundantly clear as we think of a national or large regional assessment of fish and wildlife resources that transcends the state boundaries within which most goals and objectives for wildlife have been developed. The nature of the information outputs determines the nature of the analysis needed. The definition of "analysis" as applied here contains the process by which ecological logic and ecological theory is applied to basic data to produce the key information required as input to the decision process. This implies a wide variety of specific analytical packages in order to meet the requirements of various levels within the decision process (refer to Table 1). Only a subset of these packages would be applied in a particular situation.

The role of information management systems in coupling the first three logical processes of assessment to the requirements of the analysis component contain a wide variety of potential tools. In practice this "information management system" may be the cerebral "computer" of the professional resource manager. At the other extreme this includes automatic data processing tools such as computerized statistical analysis of large data sets, geobased information manipulation, and complex mathematical models.

Characterization is a component of assessment that we have chosen to define as the model describing our understanding of a particular system (ecologic, technologic, or socio-economic). The concept of "characterization" will be discussed in greater detail below. However, an important point is that characterization provides the mechanism for synthesizing existing information concerning a defined system. The arrow between the processes of characterization and inventory in Figure 3 indicates that the former provides identification of specific information deficiencies as well as providing a structure for prioritizing data requirements in the "inventory" process.

Inventory is defined as the process of acquiring new information that is not contained within the synthesis represented by "characterization." We usually think of inventory as the process by which we go into the field and collect new data, or extract new data from sources such as remote sensing products. The concept defined here may include the access of other existing data that have not been synthesized into information as described by the "characterization" process.

The component process called "classification" includes a number of elements. These concepts include designation (delineating particular areas on the ground or objects); classification (creating systems or conceptual groupings of objects or traits); stratification (recognizing layers or levels of abstraction or organization); labeling (associating symbolic codes or words with areas, objects, or concepts); and identification (determining where an unknown object or unit belongs within a classification system). The terminology in this whole area tends to be confused with a multitude of synonyms and inconsistent usages in current literature[4], and throughout current classification efforts within government and the scientific community. A recent attempt to clarify the concepts as applied to ecological land units provides a step forward (Bailey, *et al.* in press). The function of this logical component is to organize information in a systematic manner so that it can be taken in, processed, and results presented in an efficient and effective manner. In effect, this links all other components of the logical process together. It is apparent that one must structure the identification and labeling process in order to proceed with inventory. It is also obvious to the systems analyst that a logical structuring is required within the information management systems to order data input, identify components within the analytical process, and to specify categories of outputs. Similarly, the "character-

[3]Ibid.

[4]Hall, F. C. 1976. Classification, designation, identification = confusion. Regional Guide (No.) 4, USDA Forest Service, Pacific Northwest Region. 11 pp.

ization" process requires a framework within which to attack information.

COMPONENTS OF ECOLOGICAL ASSESSMENT

Once the components of the assessment process are identified, this framework can be used to survey ongoing or past activities to fit together the pieces of this rather large and complex puzzle. It also provides a framework for specifying clear objectives for each of the component processes. This framework may also provide a rationale for establishing new efforts.

I will present an attempt to describe a wide array of ongoing activities within the Fish and Wildlife Service, principally within the Biological Services Program and the Division of Ecological Services. Where I have knowledge of the relationship of particular activities of other research programs within FWS, these will be addressed as well. Only a small fraction of activities within other federal agencies or the academic community are included below because I am unacquainted with many activities that should be included here. A general reference for more details of a number of Biological Services activities referenced below can be found in the annual reports (FY 75 and 76) of the Office of Biological Services, available from Ms. Barbara Alexander in our Washington office.

In discussing the activities in relation to each component process of assessment I will refer to three methodology focuses discussed above in Resolution Considerations. Most activities can also be related to what I defined as the "site-species," the "regional-species," or the "regional-ecosystem" approaches (refer to Table 3).

Assessment Systems

Several major activities have addressed all components defined in the ecological assessment process. These include the implementation and refinement of the Habitat Evaluation Procedures by the FWS Division of Ecological Services by the Project Impact Evaluation Group, the Coal Project, and the Cooperative Instream Flow Service Group of the Western Energy and Land Use Team. These integrated activities will be discussed by components of the logical diagram.

By far the most advanced activity in terms of problem identification, methodology development, testing and implementation is the scope of the Habitat Evaluation Procedures (U. S. Fish and Wildlife Service, 1976). The Division of Ecological Services has dominated in developing a methodology for quantifying and displaying the impacts of proposed water developments on fish and wildlife resources, in specific response to the "Principles and Standards" promulgated by the U. S. Water Resources Council. These procedures provide a structured multi-objective framework for water-resources planning. One of the two coequal planning objectives specified by the "Principles and Standards" is "environmental quality" (EQ), and the effects of any proposed water-resource plan on EQ must be assessed quantitatively. The recently established Project Impact Evaluation Group (Fort Collins) has had lead responsibility in the Fish and Wildlife Service for implementing and refining the (terrestrial) Habitat Evaluation Procedures in cooperation with other FWS programs and with other federal and state agencies. Another responsibility of this group is to develop procedures for evaluating aquatic habitats. This approach to the assessment-system process is focused on the "site-species" level of resolution and is intended to address "regional-species" assessments at a lower level of accuracy. The strategy contained within the approach to terrestrial habitat evaluation can be described by three successive elements as follows:

Element I

Communities are defined on the basis of plant associations. A set of wildlife species is selected to represent (be an indicator of) each trophic level within each community. We tend to select vertebrate species and also tend to select species for which the most published information is available. For each one of these species the life requisites are determined. The requirements for food, cover, water, reproduction and any other special factors are then graphically related to some measurable attribute(s) of the landscape unit. These are what we call "transformation curves" in which the ordinate is given in a system of increments of 0 to 1 (labeled "habitat suitability index") and the abscissa is some range of values of a measurable attribute such as percent canopy closure, size classes of forest trees, number of canopy layers, etc. The type of information found on the abscissa of these graphic relationships falls into three general classes and are developed for each community type of vegetation or other surface-cover category. An underlying assumption that needs to be refined further and documented is that the scaling factor of the ordinate (from 0 to 1) is related to a specific ecological "value," such as population size for the species, standing crop, productivity, or some other ecological "objective" for the species. An

example is fully described below (characterization).

The first class of "transformation curves" is what we call "sample-point determinations" and contains traits that are measurable on the ground or in the stream within an on-site surface-cover unit. Class Two includes juxtaposition and size relationships of the surface-cover units. These relationships are extractable from remote-sensing sources. Class Three involves the relative abundance of the particular surface-cover type within a study area.

Element II

A matrix is developed from the particular values of habitat-suitability indices for all species and all cover types and for all habitat components. This matrix indicates the current ecological status for a particular site as extrapolated from the previous analysis based upon suitability for indicator species. Several things are developed from this matrix. One is the projection of future suitability indices with or without the development of the area by particular project. The second use of this matrix is to develop the "habitat unit values": the point at which value judgment is added to the basic ecological "characterization." To accomplish this process, the matrix is summed by surface-cover class. This information in its raw form gives the measure of "ecological dependency." The specific process for this matrix manipulation has several alternatives that are under current consideration.

"Habitat unit value" is derived from this basic summation by a process that weights a number of judgments about the community or cover class. These considerations include: a) the vulnerability (resiliency) of that particular class to the specific action proposed; b) the replaceability of the unit in terms of natural successional processes or through manipulation and reclamation; and c) the regional scarcity or abundance of the particular class.

Element III

This element builds upon the basic information obtained in the analysis of habitat suitability indices from a species perspective, rather than from a community or surface-cover-class perspective (step 2). Models are built which weight the importance of the various habitat components in terms of the objective defined for the population (such as standing crop or productivity). These species-based models are then used to define the habitat capability or management potential of a given site. In short, these models provide a diagnostic tool by which the various alternatives for mitigation or compensation can be quantitatively assessed. Thus the species models integrate requirements over as many communities or cover classes as a particular indicator species is known to require or utilize.

The Biological Services' Coal Project, through the Western Energy and Land Use Team, is developing and applying an assessment methodology best described as a "regional-species-level" approach. Two major goals of this activity are (1) to develop a workable ecological impact assessment methodology having particular reference to the complex problems associated with surface coal mining and (2) to provide information and an analytic capability to a pilot user group (the Fish and Wildlife Service Billings Area Office). Specific objectives are: 1) to identify areas that are unsuitable for coal mining from an ecological basis; 2) to develop a process, built on a set of ecological criteria, for addressing the sequence of mining within coal-development areas; and 3) to establish scenarios of post-mining reclamation, with procedures to enhance wildlife populations and their habitats by ecological region. The geographic focus for these activities is the Powder River Basin of Montana and Wyoming. The strategy of this assessment system has been to develop an approach that interfaces with the "site-species" level of analysis described above (Habitat Evaluation Procedures), and test the use of the aquatic assessment procedures developed by the Cooperative Instream Flow Service Group (described below). Classification specifications have been developed jointly between the Billings Area Office, National Habitat Assessment Group, Project Impact Evaluation Group, and the Western Data Support Center--with input from other technical specialists of the Western Energy and Land Use Team. The implementation of inventory procedures has focused primarily on interpreting remote sensing products provided as one output of the Western Data Support Center. Characterization efforts include synthesizing a number of external projects by members of the Western Data Support Center and other members of the Western Energy and Land Use Team. Some of these studies include the development of bibliographies of existing information about the Powder River Basin and analysis of specific relationships between selected wildlife species and their habitat requirements, the latter study being performed by the Denver Wildlife Research Center and the Northern Prairie Wildlife Research Center. Information

management systems being developed in conjunction with these activities have been a combination of in-house efforts by the National Habitat Assessment Group, Systems Application Group (Western Energy and Land Use Team), and contractual development by the Federation of Rocky Mountain States (see further discussion under Information Management Systems below). Analytical procedures are being developed by external projects, the Systems Application Group, and other in-house components of the Western Energy and Land Use Team.

The Cooperative Instream Flow Service Group has developed a methodology for assessing altered instream flow regimes on aquatic wildlife species (Stalnaker, in press) by using the "regional-species" level approach. A weighted usable area is determined for each species by month and by life history stage pre- and post-alteration. The weighted usable area is based on the physical stream parameters of depth, velocity, and substrate; on the biological parameters of electivity curves for the above-named physical parameters by life history stages by months; and on hydrologic models of open channel flow. Weighted usable area may be converted to standing crop biomass if so desired. Using this model one can identify limiting times of the year and critical life history stages of selected species with respect to altered instream flow regimes and predict impacts of various proposed instream flow alterations in any part of the country. This approach is presently considered the prototype for similar systems to be used by the Project Impact Evaluation Group in their Habitat Evaluation Procedures for aquatic systems, and by the BSP in the Coal Project Test Areas. The CIFSG methodology is also being successfully used by states in assessing their present instream flows; projects in eight western states are testing this approach for the FWS.

Analysis

The project led by Dr. Jack E. Gross of the Systems Application Group, Western Energy and Land Use Team, attacked the problem of relating the projected impacts on fish and wildlife resources within the Department of Interior prototype oil shale program in the Piceance Basin of Colorado. Some of the analytical methods developed by his project offer promise in bridging the gap between "regional-species" considerations and "site-species" considerations. Modifications of these analytical tools are being applied as one component of the assessment system to be used in the western Coal Project activities discussed previously.

A number of specific analytical tools have been developed within the Biological Services Program that represent pieces of the analytical process. Some of these include a state-of-the-art methodology for the estimation of population density from line-transect information for "intensive site" uses. Another project sponsored by the coal effort has been to apply a working, ecosystem-level simulation model to the areas of the northern Great Plains subject to surface mining of coal. This project is being done by the Natural Resource Ecology Laboratory at Colorado State University, utilizing the "ELM" model developed under the Grassland Biome Project (IBP). This is an attempt to identify the potential application of a whole-systems model to specific resource management questions.

Information Management Systems

The development of this component of the assessment process identifies the clearest opportunity to cooperate between various agency efforts. If we can standardize the format procedures and protocol between the various requirements, we have made the most significant step toward truly integrating assessments for the maximum benefit of our public. I am encouraged by the progress I have seen in the last year toward achieving this objective of interagency liaison and coordination, both at the Washington office level of our various agencies, but also in the cooperative working environment typified by the activities in Fort Collins.

The problems of training personnel for maintaining and implementing computer-based information management systems are numerous and I will not attempt to expand upon them here. The interested reader is referred to the design criteria for geobased information management that is being developed within the Fish and Wildlife Service (Wilcott and Gates in press.) The development of this system has been achieved through a side-by-side contractual arrangement with the Federation of Rocky Mountain States, sponsored by the BSP Coal Project. We have supplemented this with Fish and Wildlife Service people from WELUT and with technical advice from the Division of Ecological Services (PIE). A variety of technical papers concerning this information system are available through the Coal Project. This information-management capability is being implemented in cooperation with one of our operational field units, the Billings Area Office, and is being implemented at that site (see Assessment Systems).

Another major activity has been to develop of the Alaska Information Management

Systems through the Habitat Analysis Project of the Biological Services Program. An interim geobased information system was installed by the Systems Application Group in the Alaska Area Office, in September of 1977. The objective of this activity is to address needs across all programs represented in the Alaska Area Office of the Fish and Wildlife Service. Further development of information management components is jointly guided by the Alaska Area Office and the Habitat Analysis Project. The products of a geobased information system developed by the Federation of Rocky Mountain States in conjunction with WELUT will be some of the first additions to the current Alaska capability. The Alaska Information Management Systems is designed as a prototype to further articulate the requirements of our operational people. These requirements relate to the types of information, resolution, accuracy, and format required to provide ecological predictions and basic data to Fish and Wildlife Service programs and their clientele.

Characterization

In a previous section (Logical Process for Assessment) I have summarized our working definition and purpose for the concept of characterization. In summary, characterization provides the framework and contains the synthesis of existing ecological understanding as a component of the assessment process. An ecological characterization embodies the following elements: 1) The assessment and integration of user needs into the development of the characterization; 2) The establishment of spatial boundaries for ecosystem units in a hierarchical manner; 3) The creation of conceptual models that provide mechanisms for identifying and integrating structural components and functional processes within units of the ecological system; 4) The synthesis of all relevant qualitative and quantitative data within the framework of the conceptual model; 5) The development of a structured data base for synthesized information; 6) The identification of information deficiencies within the system; and 7) The construction of a framework for developing predictive models based on available information.

The needs of users and the status of available ecological information for synthesis varies throughout the geography of the country. Thus, different BSP projects have put different priorities on elements within the characterization process.

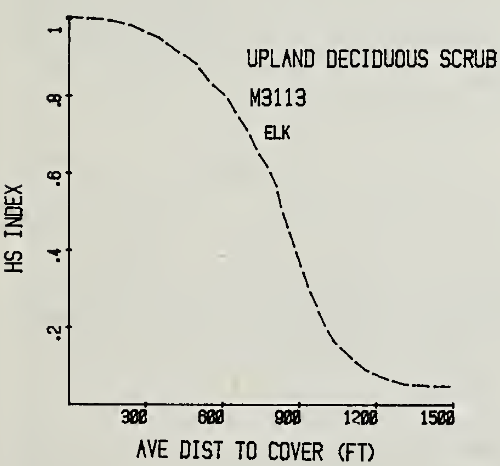
The majority of the elements of characterization are self explanatory. However, some additional comments on the philosophy of approach to the establishment of spatial boundaries and conceptual models is appropriate. The fundamental premise of guiding the establishment of operationally definable spatial boundaries for ecosystem units is an essential element. The approach has been to follow the basic concepts of regionalization (Bailey, et al. in press), as applied to major ecosystem types. For upland ecosystems, the "ecoregion" concept presented by Bailey (1976) has provided a useful framework for several activities that will be described below. For estuarine and near-shore marine systems, a coastal regionalization has been developed (Terrell 1977). For riverine ecosystems, an interim regionalization has been developed by the Cooperative Instream Flow Service Group (in press).

Specific approaches to development of conceptual ecosystem models are being addressed in several ways. A process which builds upon a "word model," which describes the functional interrelationships of major components in a defined ecosystem (Brown, et al. 1970), followed by a diagrammatic representation of the components and their interactions, which provides the structure for the development of mathematical models has been found to be useful (Coulombe and Brown 1970). A similar approach to the development of the ecosystem conceptual framework for this process has been sponsored by the Coal Project of Biological Services, which will be described in more detail by Dr. James States in this workshop. A matrix approach, as one partition of conceptual-model development, has been found useful in structuring information bases in the characterization process presently being conducted by the BSP Coastal Ecosystem Project.

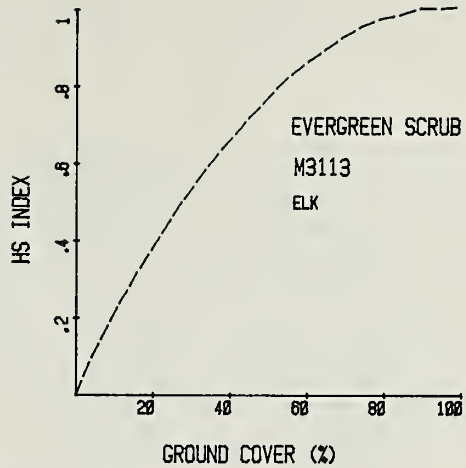
Major efforts in conducting characterization studies that deal with the "regional-ecosystem" level of resolution for assessment are provided by the Coastal Ecosystem Project. These studies are funded by pass-through funds from the Environmental Protection Agency. The four coastal areas presently being characterized are: 1) the Chenier Plain on the Gulf of Mexico; 2) the Sea Islands along the Georgia and South Carolina coast; 3) the Pacific Northwest, from northern California to Puget Sound; and 4) the coast of Maine.

The characterization process applied to the "site-species" level has been described under the current approach of the Ecological Services Division in implementing the Habitat Evaluation Procedures. (See above, Assessment Systems). Further definition of the characterization process related to implementing the HEP procedures have been demonstrated[5]. The

defined ecosystem unit was the Ponderosa Pine-Douglas Fir Forest Section M3113 as defined by Bailey's ecoregions (Bailey 1976). Nolde summarized the literature on the habitat requirements of elk (Cervus elaphus) with the conceptual model of transformation functions as the guiding framework (see discussion above, Assessment Systems). Surface-cover components within the ecoregion (M3113) were stratified into six major types: coniferous forest, upland deciduous forest, evergreen scrub, upland deciduous scrub, mountain grassland, and mountain meadow. Life requirements for elk were then summarized for each of the vegetative cover types for the following categories of life requisites: food, hiding cover, thermal cover, water, interspersion and juxtaposition of vegetative types, movements, reproduction, and human disturbance. The criteria developed from life requirements are applied to the conceptual models that relate an index of habitat suitability to specific habitat elements; examples are given in Figure 4. The next step is to convert these graphically represented functions to mathematical expressions, which are then synthesized into a predictive function for the overall habitat suitability of a given land unit for elk, including each vegetative-cover type[5]. The process described above may be applied to the guild or life-form-group concept as defined by Jack Ward Thomas (Thomas et al. in press); the selection of a spokesman or indicator species for a particular wildlife group may be implemented by the same process elements of the Habitat Evaluation Procedures.



[5]Nolde, M. J. 1977. Terrestrial habitat characterization: Ecoregion M3113 (Ponderosa Pine-Douglas Fir Community). Report to U. S. Fish and Wildlife Service, Division of Ecological Services, Project Impact Evaluation. Mimeo. report. 200 pp.



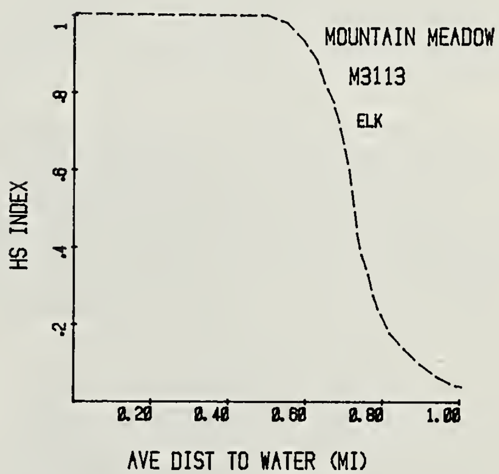


Figure 4.--Examples of transformation curves used in the Habitat Evaluation Procedures characterization process (after Nolde 1977). The ordinate is the habitat suitability index; the abscissas relate different habitat elements for the elk (Cervus elaphus) in ecoregion M3113 (Ponderosa Pine-Douglas Fir community). Examples include habitat elements from three vegetative components of the ecoregion (see text for further explanation).

Inventory

In the logical relationships between the components of the assessment, a major role of the characterization process is to define the elements of information required from the inventory function. The resolution specifications (spatial resolution, precision, accuracy) are defined in the (here unstated)

details of the assessment systems and their characterization processes. I point that out here as some specific examples to demonstrate the relationship of certain activities to the overall logical process model.

The identification of habitat elements in the Ecological Services HEP process is a prime example of the "site-species" level of resolution for assessment. Specific inventory requirements are identified as they are fitted into the conceptual-model-building process. The abscissas shown in Figure 4 are such examples of inventory requirements. Quantifying the requirements for accuracy and precision in measuring these inventory components to meet user requirements (Division of Ecological Services 1977) can be achieved by sensitivity analysis of the mathematical models that include these parameters[5].

The required parameters for inventory in the "regional-species" level of assessment are well defined in the riverine assessment process developed by the Cooperative Instream Flow Service Group (in press).

A major activity of the Fish and Wildlife Service that implements the inventory process is the National Wetland Inventory Project. You will hear a presentation on this project during this workshop, so I will not elaborate the details here. The first focus of the National Wetland Inventory has been to provide a framework (classification) for implementing a nationwide inventory of aquatic (deep water) and wetland habitats (Cowardin, et al. 1977). The framework is designed to identify major ecosystem types by delineating their components. The framework provides information that can be related to "intensive site" or "site-species" assessments. The products of the current National Inventory will provide information to a degree of resolution that will be useful to "regional-species" and "regional-ecosystem" levels of ecological assessment.

A number of efforts are defining methodologies for inventory. The evaluation of the role of current remote-sensing technology in renewable-resource management has received the most attention. These activities span a wide range of federal agencies, including several BSP projects. From my perspective, the criteria for determining appropriate approaches within the field of remote sensing technology for renewable resource assessment are defined within the logical-process context of ecological assessment.

[5] Ibid.

Classification

The function of classification activities in organizing information has been described above (A Logical Process for Assessment). There is a tremendous amount and wide scope of information required in today's resource management decision-making. Relatively few portions have been classified in a way that will meet our long-range information needs. The FWS' efforts have, to date, focused mostly on classifications needed to support land surface inventorying. Our National Wetland Inventory Project commissioned the production of a new classification to replace the more limited one of Martin et al. (1953). After two years and extensive review, an operational draft is now in print (Cowardin et al. 1977); this is being applied to accomplish the inventory (discussed above).

The Cowardin et al. system is being extended by work now in progress. A cooperative effort by the National Wetland Inventory Project, operational FWS personnel, and the National Habitat Assessment Group will add components for dealing with riparian habitat types. These will spatially overlap the wetland units, and partially extend into upland areas. Another effort is underway by our Eastern Energy and Land Use Group, and National Habitat Assessment Group, and Project Impact Evaluation staff to develop a classification for use with the water mass in aquatic systems. (The Cowardin et al. system already includes an adequate treatment of bottom types in aquatic units.) In addition to the above efforts, other classifications are in wide use. FWS will attempt to synthesize these classification components and a limited number of other classifications into a single, consistent system. This effort is planned for about 1981.

Conclusions

I would like to summarize several considerations that perhaps are self evident from the discussions in this paper. These are presented in relationship to the requirements for goals and specific objectives for developing a systematic process for ecological assessment.

My first observation should be considered axiomatic. That is, we must focus attention on selected ecological predictions as specified by user requirements within the decision-level hierarchy. We can develop criteria by which we may measure the acceptable level of achievement for specific requirements. This level should represent sufficient attainment as opposed to a "basic, practicable technology."

My point is that when we wear the hats of technical specialists, we have a tendency to develop procedures and methods that are more precise, more accurate, and hence more costly than is warranted by the desired use of such information for a decisionmaker. As a general rule, this trade-off can also be equated to timeliness of the information and availability to the user. I do not suggest that information overload (not to be confused with data overload) is currently a significant problem in the natural resource field--quite the opposite. I direct my remarks to the design of new approaches.

The second observation is that the goal of a holistic ecological assessment can be effectively addressed through the design of a "top down" conceptual framework. I offer two items for your consideration in support of this observation. On one hand, the level of integration of the predictions created through an ecological assessment with similar, parallel paths from technological and socioeconomic perspectives must arrive at a common basis of understanding for the decisionmaker (Odum 1977). On the other hand, the conceptual framework I have suggested in this paper proposes a hierarchical relationship between the information requirements at several generalized (and also hierarchical) levels of the federal decisionmaking process.

My third observation is that the goal of the holistic ecological assessment is efficiently achieved by a structured synthesis of the understanding of ecological structure and function provided by key elements from the reductionism approach (Holling 1977). The structured framework should be developed within the constraints of my first observation (a selected focus specified by users) and the context of the second proposition (the holistic goal addressed through a "top down" framework). In support of this conclusion, I would simply offer the basic premise of the scientific method, as specifically articulated for the "new ecology" (Odum 1977).

The last observation I venture to suggest is nothing more than a pragmatic assessment of the nature of human motivation and the scientific method. Working hypotheses, stated in a testable manner, are appropriate targets for proceeding toward specific objectives in developing an ecological assessment approach. It is a well known fact that much, if not indeed most, of the progress in the field of ecology has been stimulated by the proposal of controversial concepts or hypotheses and the subsequent efforts to refute these hypotheses (Odum 1977). The concepts, logical approaches, and elements within each logical process presented here will, I hope, stimulate these energies. However, I will be the first to admit that these "hypotheses" have not been clearly stated in a testable manner. That is clearly a further step.

I think we all can agree that some set of explicit working hypotheses are necessary as we collectively move toward the objectives of integrated ecological assessments, of which one component is integrated resource inventories. Certainly one benefit of this approach is to provide a framework within which the activities of the various participants can provide technical innovation in their approaches. At the same time administrators can cope with the increasingly complex task of identifying duplicated effort.

I would like to conclude my remarks with the reminder that the ideas presented in this paper are by no means my own. I take the consequences of attempting to synthesize a large number of innovations or perspectives developed by other people--several of whom are present today. To those of you whose ideas I have misrepresented, I offer my condolences. To others whose ideas I have neglected, I offer my sincere apologies. To those of you who are deeply involved in bringing to fruition various portions of the ecological assessment process, I offer my enthusiasm. And to those among you who await to apply the results of our collective efforts, I offer my best wishes.

ACKNOWLEDGEMENTS

There are numerous contributors to the concepts and processes I have attempted to synthesize and relate in this paper. By not recognizing specific individuals, any criticisms of the intent of my presentation or any specific points will fall directly upon the author. And I shall feel free to share the identity of specific contributors with those who either support or refute the ideas presented here.

The members of the various components of the Western Energy and Land Use Team, personnel of the Rocky Mountain Forest and Range Experiment Station, the Bureau of Land Management Denver Service Center, the Project Impact Evaluation staff of the FWS Division of Ecological Services, personnel of the Denver Wildlife Research Center, various people of the Biological Services Program representing all projects, and representatives of the operational arm of the Fish and Wildlife Service have all contributed to the ideas that I have attempted to merge here.

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The Opportunity Spectrum Concept and Behavioral Information in Outdoor Recreation Resource Supply Inventories: A Rationale[1]

B. L. Driver and Perry J. Brown[2]

Abstract.--The paper describes five types of information needed for balanced outdoor recreation resource (ORR) planning and management decisions. The role of behavioral information in defining user preferences is explained within a "recreation opportunity demand hierarchy." Components of that hierarchy are related to ORR supply inventories by showing how preferences for activity opportunities, for specific features of physical settings, and for specific psychological outcomes (that give satisfaction) were incorporated into a system that was developed to classify wildland areas according to their potential for providing six broad types of recreation opportunity. The system is based on the concept of a recreation opportunity and resource classification spectrum which is explained and related both to ORR inventory and management decisions. Using the system, land areas can be inventoried in terms of their capability of providing both activity and experience opportunities.

The most important responsibilities wildland recreation managers have are: (1) to provide recreation opportunities which are demanded and appropriate for the area being managed; (2) to prevent unacceptable damage to the resources; and (3) to protect users from serious harm. The relative importance of these three responsibilities varies from area to area.

The three purposes of this paper are: (1) to outline the types of information needed to meet the first of these responsibilities effectively and efficiently; (2) to explain why information on behaviorally defined user preferences is needed in outdoor recreation resource (ORR) supply inventories, and (3) to show how such information can be used within the context of the recreation opportunity spectrum concept.

Professional Skills Needed for Effective ORR Planning and Management

Several types of professional skills are required for integrated recreation resource planning and management. These skills are based on at least some understanding of five different areas of knowledge. These knowledge bases, with brief examples of their use in ORR supply inventories (SI's) are described below:

1. Knowledge of the natural and physical sciences to help understand the natural and physical processes within a particular environment setting. These skills are essential in SI's for assessing the physical capability of the resources to provide recreation opportunities.

2. Knowledge of administrative, legal, and policy processes to work effectively within one's own agency or organization and other social institutions. At least some skills of this nature are necessary in SI's for coordinating work assignments and for identifying which things to inventory, given an agency's roles and responsibilities.

3. Knowledge of the social and behavioral sciences to help understand outdoor recreationists' preferences and the social psychology of organizations. Understanding consumer preferences is necessary in SI's to know what is to be supplied.

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[1]This paper provides the conceptual background for another paper (Brown et al.) in these proceedings.

[2]Recreation Research Project Leader, Rocky Mountain Forest and Range Experiment Station, and Associate Professor, Department of Recreation Resources, Colorado State University, Fort Collins, respectively. Charles McConnell, Region 2 recreation staff officer, USDA Forest Service, has been a helpful associate in developing the ideas presented in this paper.

4. Knowledge of quantitative methods (e.g., basic economics, statistics, system analysis, etc.) for assessing consumer demands, handling inventory data, and other quantitative tasks.

5. Knowledge gained from problem solving experiences. This type of knowledge covers a variety of skills including those related to identifying needs for SI's, defining the SI problem, selecting the most appropriate techniques for making the SI, and monitoring the results of the decisions that are based on the SI.

While it is unlikely for any one person to be highly trained in each of these skills, training of recreation resource planners and managers has emphasized the transmission of natural and physical science skills, with quantitative and administrative skills receiving the next, but considerably less, emphasis. Relatively few natural resource professionals have had formal training in the behavioral science disciplines of sociology, psychology, political science or anthropology within a context that makes the knowledge of these disciplines relevant to wildland resource planning and management. Yet, tremendous progress has been made recently in relating concepts from the social and behavioral sciences to ORR planning and management problems (Wagar 1964, 1966, Hendee et al. 1968, Clark et al. 1971, Potter et al. 1973, Stankey 1973, Knopf et al. 1973, Peterson 1974, Randall et al. 1974, LaPage and Ragain 1974, Hendee 1974, Brown 1975, Driver 1975, Driver and Brown 1975, Driver and Knopf 1976, Driver 1976a and 1976b, Brown et al. 1976, Brown et al. 1977, Clark 1977, Hautaluoma and Brown 1978, Heberlein 1977, Stankey 1977). One of the reasons this information is not getting applied more widely is that, during the past 10 years, the state of relevant social and behavioral science knowledge has gone beyond the expertise available to implement it.

During the past decade, increasing public involvement in decision making, and growing legal and administrative costs, have affected every resource management agency. To deal with these "people-related" factors effectively, resource professionals must have greater skill in applying knowledge from each of the five areas listed above.

The remainder of this paper attempts to show how one type of behavioral information (psychologically defined user demands) can be used to supplement the other types of information needed for ORR supply inventories. We begin by proposing a behavioral interpretation of what constitutes a recreation opportunity. Then, we divide the concept of recreation preference or demand (but not necessarily economic demand) into several related components. Finally, using the concept of the "Recreation Opportunity Spectrum", we suggest how these components can be used in ORR inventories.

How Are Recreation Opportunities Defined

The words "recreation opportunity" imply that consumers have preferences to guide their choices, and that they have real options to choose from. The basic question guiding ORR supply inventories is: What is the inherent capability (i.e., potential) of an area to produce those recreation opportunities which are preferred (or demanded) most highly? This can be further reduced to: For what types of preferred opportunities is the inventory being made?

Practically all ORR inventories have been based on the criterion that the resource base should be inventoried in terms of its potential to provide opportunities for specific recreation activities. However, for reasons explained elsewhere (Driver and Tocher 1970, Driver and Brown 1975, Driver 1976a), it is now widely recognized that the concept of activity opportunity, although necessary, is inadequate for the formation of meaningful management objectives or for quantifying the "products" of recreation management systems. If activity opportunities are an inadequate indicator of management system performance, they are also inadequate as the basic guide for ORR inventories.

We would like to propose some behavioral science parameters for defining, inventorying and managing recreation opportunities. To explain these parameters, we will describe two conceptual frameworks on which we have built our thoughts about design of an ORR inventory system. The first hierarchically defines four levels at which recreation opportunities are demanded. That schema also relates demands for activity opportunities to demands for recreation opportunities defined by psychological parameters. The second explains how a spectrum of behaviorally defined opportunities can be inventoried.

Recreation Opportunity Demand Hierarchy

We have found it useful to separate recreation demand into four associated components which are defined in terms of specific types of opportunities that are demanded (Driver 1977). Because users are more aware of their demand for the first type of opportunity than they are for the second, third, or fourth types, we have labeled the schema the "recreation opportunity demand hierarchy." It is hierarchical because this differential awareness of the demand for

each component makes it increasingly difficult to measure the demand as we move from the first to the fourth level. Each level, or component, is explained below, with special attention given to Levels 2 and 3, because these two components of demand will be used to explain the concept of a recreation opportunity spectrum in the next section:

Level 1. Demands for a recreation activity, such as to camp in a wilderness area, to picnic with one's family, to walk an interpreted nature trail, to whitewater canoe, to downhill ski, and so on. These demands have been the focus of most ORR planning and management decisions.

Level 2. Demands for opportunities to experience those situational attributes (or elements) of the physical setting, of the social setting, and of management settings (actions) that characterize quality of preferred recreation environments. In combination, these three types of "setting preference" define the total environmental setting that is preferred for a specific Level 1 activity opportunity. For example, a wilderness camper might desire an opportunity to visit a remote area (physical setting), with few people (social setting), where there are few restrictions on his/her behavior (management setting). Or, a downhill skier might desire that slopes be fairly steep (physical setting), lift lines not be too long (social setting), or lift prices not too high (management setting). These attributes (scenic resources, different concentrations of people, various levels of physical development, etc.) are both inventoried and managed to provide opportunities for quality recreation experiences. For example, the desired attributes of the physical environmental setting are a major consideration in ORR inventories. Without these environmental settings, there would be no recreation opportunities. However, these Level 2 demands do not exist in and of themselves; they exist because of the utilities (satisfactions and benefits) that are demanded at Levels 3 and 4.

Level 3. Demands for opportunities to realize specific psychological outcomes that are desired from an activity opportunity and its associated preferred environmental setting. This demand is for the opportunity to experience those psychological outcomes (or states of mind) that are valued highly because they give satisfaction. Examples of specific psychological outcomes include: Enjoyment of the out-of-doors, applying and developing skills, strengthening family ties and kinship, learning, getting exercise, exploring, reflecting on personal values, temporarily escaping a variety of adverse stimuli back home or at work, taking risks and so on.[3/] For example, a wilderness hiker might desire few people in order to experience solitude, among other things. A family picnicker might value highly the feeling of family togetherness. And a walker of an interpreted trail might engage primarily to learn.

An activity opportunity is certainly not demanded to realize only one preferred type of outcome. Instead, many of these satisfying outcomes are realized simultaneously from participating in a particular activity (Wagar 1964, Driver and Tocher 1970, Hendee 1974, Brown et al. 1977, Hautaluoma and Brown 1978). However, our current research indicates strongly that a "bundle" of from four to eight outcomes is valued most highly as reasons for participating in a particular activity, with the number of these most highly preferred outcomes varying from activity to activity.

We refer to the bundle of most highly valued outcomes as the overall "experience opportunity" that is desired; users desire to experience that bundle (of most preferred outcomes) which is relatively unique to the activity in which they have decided to engage. These experience opportunity preferences will, therefore, vary from activity to activity. They also vary somewhat from user to user within an activity. However, the within-activity differences are usually less than the between-activity differences, or fewer different activities would be chosen. For example, not too many people engage in picnicking to seek thrills or take risks, but downhill skiers do "demand" those types of outcomes along with their associated desires to exercise, apply and develop skills, enjoy the outdoors, be with and observe other people, gain social recognition, escape the pressures of everyday life, and to realize other highly valued outcomes that define a quality skiing experience to them. Some downhill skiers will value some of the psychological outcomes within the bundle more highly than

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[3/] In other papers we have referred to these desired psychological outcomes as specific types of desired satisfaction. Our logic is that many things (e.g., enjoying the smells and sounds of nature, scenic beauty, taking risks, exercising, relaxing, etc.) give pleasure to wildland recreationists and that each provides a different type of satisfaction. We believe that the satisfaction gained from teaching one's children an outdoor skill is different from the satisfaction received from feeling rested, or from being recognized socially for having done something. Within that context, we view specific desired psychological outcomes and specific types of desired satisfaction as being synonymous.

other skiers will. However, the set of outcomes within the bundle does not seem to change much from area to area for a particular activity if the Level 2 attributes remain reasonably similar.

Level 4. Demands for opportunities to realize the benefits that flow from the satisfying experiences, with benefits defined as enhanced (or improved) subsequent performance or effective functioning after having participated. These subsequent improvements in behavior can be reflected as improved states of the individual who participated or of society because of that participation. For example, the solitude experienced by the wilderness hiker might lead to enhanced work performance. Family togetherness of picnickers might lead to enhanced family solidarity. The learning of the interpretive nature trail walker might lead to greater commitments to conservation efforts. And, the exercise realized from a long hike might lead to health-related benefits.

ORR inventories are currently being made in terms of some of these benefits, such as physical fitness-testing trails for health benefits. However, most of these parameters are still defined intuitively or subjectively given the state of our knowledge about these benefits and the environmental settings in which they are produced.

Our research, and that of our associates, is showing: That the Level 3 psychological outcomes can be identified; that the relative importance of outcomes preferred from different activities can be measured reasonably accurately; and that their relationship to (and dependency on) the Level 2 attributes can be established (Lucas 1964, 1970, Lime 1971, Clark et al. 1971, Mandell and Marans 1972, Potter et al. 1973, Stankey et al 1973, More 1973, Talhelm 1973, Knopf et al. 1973, Stankey 1973, Peterson 1974, LaPage and Ragain 1974, Driver 1976a and b, Driver and Knopf 1976, Marans et al. 1977, Brown et al. 1977, Hautaluoma and Brown 1977, Driver and Cooksey 1978). Currently, we have instruments for measuring 40 specific (20 general) types of outcomes that are commonly demanded by large numbers of users and which are relevant to management decisions. The managerial relevance of information on the Level 3 recreation opportunity demands is described in some detail in another paper.[4/] The relevance of those Level 3 demands to ORR supply inventories will now be discussed within the context of inventorying the recreation potential of resources along the "Recreation Opportunity and Resource Classification Spectrum (RORCS).

Recreation Opportunity and Resource Classification Spectrum

The preservation or expansion of personal freedom of choice is an underlying tenet of any republican-democratic form of government. That philosophy has guided management of practically all service delivery systems in our society, whether they be housing, transportation, education, clothing, or medical markets, that define the products or services delivered. The social goal of freedom of choice applies also to outdoor recreation markets; people should have as wide a variety of opportunities to choose from as is possible. In fact, this goal has led to considerable public sector subsidization of outdoor recreation to help assure that a wide variety of opportunities will be made available to many different types of users.

A problem associated with the attempt to provide a variety of recreation opportunities has resulted from reliance on the activity definition of opportunity. That approach has tended to nurture the idea that managers should attempt to provide as many activity opportunities on a given area as possible, rather than attempt to provide those experience opportunities which are most appropriate for the area. The activity approach to ORR management, therefore, has not adequately differentiated the products or services provided because the psychologically defined Level 3 outputs have generally not been considered. These psychological dimensions of opportunity must be considered for clear differentiation between activities, such as between canoeing on a calm urban lake and canoeing on a white water wilderness stream. They also must be considered when attempting to decide which settings are most appropriate for particular opportunities.
For these reasons the concept of a recreation opportunity spectrum, which incorporates both the idea of activity and experience opportunity, is becoming more widely accepted (Wagar 1966, Lloyd and Fischer 1972, Stankey 1977)[5/].

4/ Driver, B. L. and P. J. Brown. 1978. Relationships between economic and non-economic components of recreation demand: a managerial perspective. Forthcoming as Research Pap., USDA, For. Serv., Rocky Mtn. For. and Range Exp. Stn., Fort Collins, Colo.

5/ In a personal communication, Roger Clark of the USDA Forest Service's Pacific Northwestern Experiment Station in Seattle, has also discussed the need for use of the recreation opportunity spectrum concept.

A recreation opportunity spectrum is based on the idea that there is a continuum of opportunities that range from one anchor, or polar, point on the spectrum to another. To develop a spectrum, the major tasks are: (1) defining the two anchor points and what lies in between, and (2) establishing criteria that differentiate the characteristics of opportunities at one point of the spectrum from other points on the spectrum.

Stankey (1977) has pointed out that the anchor points of the spectrum can be defined in many ways, including: high user equipment cost to low user equipment cost activities; high to low agency development cost activities; high versus low space requirement activities; concentrated use to non-concentrated use activities and so on.

We used three criteria to define the opportunity spectrum which we believe can be a helpful guide for ORR planning and management decisions. They are:

1. The spectrum should include an array of activity opportunities that vary in the extent to which they reflect the polar attributes that define the spectrum.

2. The spectrum should include a diversity of experience opportunities which vary in nature from one pole of the spectrum to the other.

3. The spectrum should specify the characteristics of the environmental settings that are appropriate for the different types of activity and experience opportunity located at different points on the spectrum.

In addition, we attempted to develop a spectrum which would: have intuitive appeal to managers and give relevant and useful results; be adaptable to the land planning processes (or models) used by different agencies; give consistent results when replicated by different people on the same area; and not be too costly or difficult to implement.

Using these criteria, we modified the spectrum which was proposed by Gordon Sanford as a basis for Forest Service ORR inventories.[6] The resulting spectrum does not use the concept of experience levels as Sanford's did and is easier to apply. It is shown below:

The characteristics of the different points on the spectrum are explained fully in the Brown et al. paper in these proceedings. Briefly, however, the different points of the spectrum are defined in terms of relationships between the Level 1, 2, and 3 demands. For example, the polar points of Modern-Urban and Primitive were defined in terms of specific activity and experience opportunity potentials, with these potentials being determined by the presence or absence of specific and facilitating Level 2 attributes. The attributes used to define each anchor point were: size, remoteness, naturalness or the relative degree of man's irreversible influence, presence of physically and mentally challenging features and barriers to travel. These requisite polar attributes define the inherent capability or potential of the resources to support Level 1 activity and Level 3 outcome opportunities that are appropriate for a particular point on the spectrum. For example, if an area is inventoried as Primitive, it would have a high potential for activities that do not require motorized equipment, are associated with relatively low density and non-concentrated use, are challenging and require a high degree of woodsman skills and physical stamina, and are dependent on a physical environment that is

[6] The Sanford ORR Inventory System, also known as the RII (Recreation Inventory Instructions), and other ORR inventory and classification systems, are briefly reviewed in a companion paper in these proceedings by Brown et al. Also, see Forest Service Manual, Section Nos. 2303.1 and 2331.11c, as of November 1977.

Modern-Urban	Concentrated	Rustic	Semi-Primitive motorized	Semi-Primitive non-motorized	Primitive

Recreation Opportunity and Resource Classification Spectrum

Figure 1. Proposed Recreation Opportunity Spectrum

essentially unmodified by man and is of sufficient size, topographic configuration or vegetative composition to qualify some parts of it as being remote. The experience opportunity bundle for the Primitive classification would include opportunities for realizing psychological outcomes such as competence testing; experiencing solitude, isolation or privacy; sensing tranquility; realizing a closeness to nature; and perhaps chancing somewhat unpredictable, or even risky, situations.

The experience opportunities must be considered explicitly to specify which activity opportunities are most suited for a particular point on the spectrum and to differentiate between activities. For example, hiking, backpacking, fishing, hunting and other activities can occur at several (to all) points on the spectrum. But hiking in domesticated environments is not the same experience as hiking in a remote primitive environment. The types of psychological outcomes that are realized might differ because of different use levels, levels of development, amounts of unnatural sounds, and so on. Only by defining the types of experience opportunities that are most likely and possible in a given environment can an explicit differentiation between activities be made. In a nutshell, this statement is the essence of our paper.

Our current research is addressed to refining knowledge about relationships between the Level 1, 2, and 3 preferences at different points on the spectrum. Working with ORR planners and managers we have made considerable progress in those efforts. Although additional research and management input is needed to define more clearly the Level 1, 2, and 3 demands and their interrelationships, the spectrum concept is now a part of the Land Management Planning Handbook (R-2 FSH Section No. 1901.15) for Region 2 of the USDA Forest Service and is being used in planning in that region.

The basic advantages of the use of the spectrum concept are that it makes explicit how the ORR inventories are made; it helps define more clearly for what the inventories are being made (i.e., it defines the recreation "product" potential of an area); and it provides the public a better means of critiquing what has been done (and of focusing discussion on their points of agreement and disagreement) in the public involvement process. For example, recreation opportunities at the polar ends of the spectrum are fairly well defined in the minds of managers and users. However, it is not clear how backcountry and wilderness recreation opportunities differ or are similar. Application of the spectrum concept would provide more explicit guidelines for classifying these resources and thereby for directing public input regarding agreement or disagreement with those classifications.

The spectrum concept is also useful for later allocation and management decisions. The manager has more explicit guidelines to determine what management actions are required to modify the Level 2 attributes at any one point on the spectrum (as inventoried) to accommodate the opportunity mix he wishes to provide at that setting. Put differently, the inventory-classification spectrum can be altered by management actions (after inventory) to become a management spectrum. For example, managers can change an area inventoried as primitive to semiprimitive or, from rustic to semiprimitive, by adding or removing infrastructure, or making other changes in the Level 2 attributes as inventoried. In this way, ORR managers can use the spectrum concept to set clear management objectives regarding the specific types and quality of activity and outcome opportunities they will attempt to provide on an area given a prescribed level of management.[7/] Thereby, the user will have greater predictability over what is likely, and supply and demand will be brought into closer agreement.

SUMMARY

We have proposed that, for balanced and integrated ORR planning and management, knowledge is needed about the different components of demand for recreation opportunities. One of these components was defined as demands for opportunities to realize specific psychological outcomes that are desired and expected from particular activities. That bundle of from four to eight outcomes that are preferred most highly from a particular activity and setting was defined as a demanded experience opportunity.

We proposed that managers cannot and should not attempt to provide every type of experience opportunity on every area but instead gear management toward the provision of those demanded experience opportunities which are most appropriate for particular resources and settings.

7/The managing for experience concept has a long history in the private recreation industry. For example, the experience outcomes are similar in nature to those programmed or managed outcomes which the private entertainment enterprises attempt to deliver. Their use of the words "package of opportunities" is similar to our notion of a bundle of most preferred psychological outcomes--or an experience opportunity--that management can program itself to deliver.

This can be done by using the opportunity spectrum concept to (1) inventory ORR's in terms of their inherent potential to provide both activity and experience opportunities, and (2) set management objectives that specify what types of activity and experience opportunities will be provided at a particular location.

We proposed that the Level 3 outcomes that are valued from wildland recreation participation can be identified and their relative importance for particular activities can be measured reasonably accurately. Furthermore, we stated that, with management input and researchers working with managers, the spectrum concept can now be implemented effectively.

It was suggested that use of the spectrum concept will not only provide better guidelines for ORR planning and management decisions, it will also help managers understand better the products of ORR management than if they continue to rely primarily on an "activity opportunity" definition of recreation. Finally, use of the spectrum concept will help assure that users will have greater predictability about their wildland recreation opportunities. As consumers they will have better information about their market options.

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Data Requirements for Management of Rangelands[1]

Floyd E. Kinsinger[2]

Abstract.--Data required for planning and management of domestic livestock grazing and wild horse and burro management primarily comes from a basic soil and vegetation inventory which describes both existing and potential vegetation communities. Other resource data from wildlife, watershed, recreation, etc., are necessary to assess environmental impacts of grazing. A plea is made for development and coordination of multi-disciplinary inter-agency inventory procedures.

INTRODUCTION

Mr. Chairman, Mr. Moderator, fellow panelists, ladies and gentlemen: The title of my paper is wrong. I could not hope to discuss, in the time available to me, the "data requirements for management of rangelands" even if I knew what they were. Instead, my comments will be limited to data requirements primarily for management of domestic livestock grazing on public lands with some additional limited discussion of data needed for wild horse and burro management.

I subscribe to the philosophy that rangeland is a "kind" of land with a multiplicity of uses, just as timberland or cropland are "kinds" of land. In my frenzy to meet deadlines, develop a topic, prepare materials, etc., I fell into an old but inexcusable dogma--that rangeland and livestock grazing are synonymous. Certainly livestock grazing is an important use of rangelands--but not the only use or even the most important use in many circumstances. If I were to address the topic as listed in your program, I would discuss data requirements for wildlife and wildlife habitat management, forest, recreation, watershed hydrology, water quality, soils, and other renewable components of rangeland ecosystems. In order to do this, I would need to be knowledgeable and conversant in all of these rangeland values plus sociology, psychology, and economics. In order to prepare an environmental statement on the impacts of livestock grazing on resources and values, data is required on all of these components of the ecosystem. The need, therefore, for various resource specialists to work together as a team, pool their knowledge and expertise, to prepare multiple use management plans and comprehensive environmental statements is obvious.

I have long advocated the development of an integrated, coordinated, inter-disciplinary, inter-agency inventory procedure for renewable natural resources. Surely, we can develop a single inventory method that will meet the majority of needs for planning and management of renewable resources. A good inventory is absolutely basic to subsequent planning. My remarks pertain more to vegetation inventory, I suppose, than other inventories. Soil scientists, seem to have solved this problem with their national standard soil survey procedures. Wildlife biologists seem to be approaching standard inventory methodology between Federal and State agencies. Foresters have made some progress in this respect, particularly in timber volume estimates.

Vegetation characteristics are vitally important to a variety of resource uses and values--grazing, runoff, scenic quality, habitat, fire management--and there seems to be countless ways to inventory the botanical component of the landscape. Can't we develop a single method for vegetation inventory that will meet all our needs in resource management? Research may have a different requirement and a different level of detail and precision. But if we could just agree on common terminology, this would be a significant step forward. Particularly it would seem that the land managing agencies - primarily the Forest Service and BLM but also

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including the Soil Conservation Service, Bureau of Indian Affairs, Department of Defense, other Federal and State land agencies would benefit from a common inventory method for vegetation.

In order to develop my topic, I need to explain what I believe is a very useful technique used in BLM recently to identify data elements required for planning and management in our various resource programs. BLM launched a study several years ago aimed at determining the feasibility of automation of the data required in our resource programs. Out of this lengthy study came what we call the Strategic Information Plan which sets forth a plan and time schedule to automate a significant amount of the data and data manipulations now being done largely by time-consuming manual procedures. The Strategic Plan includes automation of data required not only in our resource programs such as watershed, wildlife, recreation, range, forestry, etc., but also includes other Bureau functions as well such as personnel, budget, equipment, etc. Part of the process of identifying data needs for these various programs and functions is through a systematic step-by-step approach which we called the Detailed Requirements Definition - DRD. After I was assigned to work on this DRD, just for the Range Management program, for 9 months, day in and day out, 5 days a week, sometimes after hours and on weekends, I had another name for DRD - "Dirty Rotten Detail".

Very simply, DRD (Detailed Requirements Definition) required that each resource program identify the data needed to accomplish their particular job and define each data element identified. I mentioned that I worked on the Range Management program; other specialists in wildlife, forestry, watershed, recreation, and other programs identified data needs and definitions for their programs. Obviously, some duplication of data requirements would occur. For example, we need to know vegetation composition for management of livestock grazing. This data element is also useful to wildlife habitat management, watershed management, recreation, fire management, and others. So part of the DRD process required that all resource specialists meet together to resolve con licts and to develop a common list of data elements, each of which is defined for a common understanding of what that data element means. The final product of this effort was a Data Element Dictionary which lists all the data elements required for the inventory of resources in BLM and provides a definition for each data element.

One might ask, which we did, "How do you begin to identify the detailed kinds of data needed to manage a resource program?" We used a technique of breaking our tasks, jobs, and functions down into finer and finer categories until we got right down to the day-to-day responsibilities of resource management. This subdivision of a task or job was arranged in a hierarchy chart (fig. 1). We repeatedly ask ourselves two questions: What do we do? How do we do it? As each task was subdivided into lower sub-tasks, we identified the data required to do each task and sub-task.

It's not as easy as my brief explanation would appear. In the Range Management program, we identified approximately 600 data elements and defined each just for inventory and resource analysis purposes. It does not provide all the data we need for resource planning and management, which is yet another package in the Strategic Plan. However, once we obtain the basic inventory data we need, along with inventory data from other resource programs, we can begin to analyze and interpret the data to arrive at multiple use decisions and accomplish multiple use management with livestock grazing and wild horse and burro management.

Ultimately, our goal is to develop specific management plans for livestock and wild horse and burro herds which will maintain and/or improve the condition of the land and resources.

Other activities within BLM, such as wildlife, recreation, watershed, will also be developing "plans" for their particular functions to serve the same purposes. We will each use much of the same basic inventory data but each activity may summarize, analyze, and interpret the data for different purposes.

For the Range Management program, we see this whole series of processes from inventory to multiple use planning as a sequence of steps as depicted in a generalized way in figure 2. Perhaps at this point it would be appropriate to list our major tasks in the Range Management program in BLM before we list our data needs to accomplish these tasks:

1. Issue licenses, leases, and permits which authorize grazing by domestic livestock on public lands.

2. Manage, protect, and control wild horses and burros on public lands.

3. Prepare and implement management plans for livestock grazing and wild horses and burros, following procedures of the Bureau planning system.

4. Prepare environmental statements describing the impacts of domestic livestock grazing.

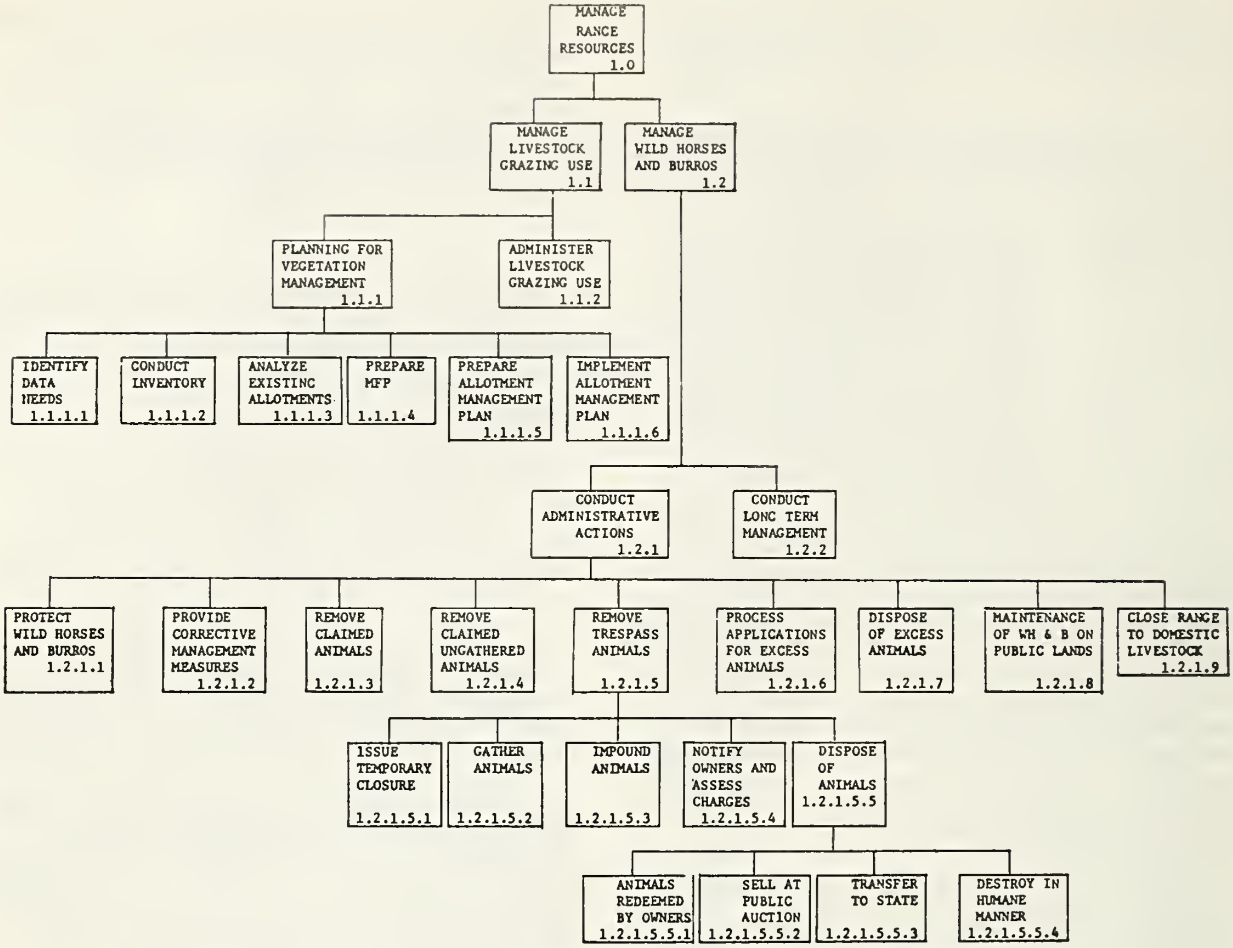

Figure 1.— Sample hierarchy chart to indicate its value as a means to determine data needs in Range Management

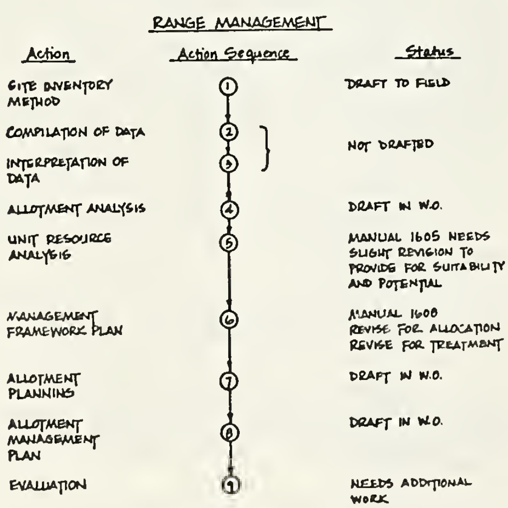

Figure 2.-- Range management planning action steps, from inventory to evaluation of activity plans.

5. Range improvement project development and maintenance (i.e. water development, fence construction, land treatment).

6. Monitor and evaluation system to determine if management objectives are being achieved.

7. Benefit-cost economic analysis of the livestock grazing management plans.

It would not be appropriate to try to list and discuss all 600 inventory data elements needed to accomplish these broad responsibilities but we need to discuss some of the major data items we require and how they are used (fig. 3).

First and foremost, a good soil inventory at the level of phases of soil series where possible at an appropriate scale (1:24,000) is basic to resource management and particularly to range management. Some of the uses and

INVENTORY	PURPOSE-INTERPRETATION
1. Soil 1:24,000 Phases of soil series	Potential Treatment Hydrology Construction Suitability Develop use plans Prepare environmental statement
2. Vetegation Production by species Ground cover Age and form class Availability for grazing Height Phenology	Allocation of vegetation Runoff and sedimentation Range condition Range trend Community structure Fire management Visual scenic value Suitability Threatened/endangered plants Develop use plans Prepare environmental statement
3. Wild Horses & Burros Number Age classes Sex ratio	

Figure 3. - - Broad categories of inventory data requirements for Range Management and possible uses and interpretation of the data.

interpretations made from soil inventory data include allocation of potential vegetation production among consumptive and non-consumptive uses for future planning purposes; capability of the soil for chemical and mechanical treatment or burning; hydrologic characteristics of the soil including infiltration, permeability, water-holding capacity, runoff, and other features such as erodability; and whether the soil is suitable for certain range improvement projects such as reservoir construction for stock-watering purposes. Soil is but one criterion for assessing suitability of the range for grazing but it's inherent productivity and erodability certainly are important factors in determining grazing suitability.

Other features, not directly related to soils but which are recorded during a soil inventory, are slope, topographic aspect, and land form. Slope is another criterion which interrelates with erodability for determining suitability of the land for grazing.

Probably of equal importance to a good soil inventory, is a good vegetation inventory. It is essential to have a detailed inventory of the existing plant community as well as the potential plant community which the soil is capable of supporting in that particular climate. One of the key data elements is production by weight for each species in the existing and potential communities. This information is used for allocation of the vegetation resource among consumptive and non-consumptive uses both in the existing and potential communities. It gives us a means of establishing carrying capacities for domestic livestock, wild horses and burros, and wildlife such as deer, elk, and antelope. The opportunity is provided to consider trade-offs among consumptive users for multiple use planning purposes. Knowing the potential plant production provides guidelines for establishing management objectives in grazing management plans. Implied in the allocation of vegetation resources among consumptive uses requires knowledge of dietary needs, species preference, and forage requirements for each herbivore by season.

Allocation of the vegetation resource among non-consumptive uses is even more challenging. Requirements for habitat cover, nesting, and all forms of small mammals, reptiles, and birds is almost unknown. But it is certain that we in Range Management cannot graze it all off with livestock and wild horses. Also, some of the vegetation resource, including litter, must be left for soil protection to prevent runoff and erosion. Other reservations of vegetation might be made for scenic quality, off-road vehicles, preservation of threatened/endangered species and other values.

Realistic allocation of the vegetation requires knowledge of its availability for different animal species. Availability includes whether the forage or browse is within reach of the foraging animal. Availability also includes whether the plant is growing out in the open and accessible to the animal.

Comparison of existing plant communities with potential communities for that particular soil and climate can be interpreted for range condition classification and "apparent" trend in range condition. I believe that range condition depends on the particular use involved on that particular area. For example, range condition for cattle grazing may be different than that for sheep, horses, deer, sage grouse, or watershed. But, the vegetation inventory data can be interpreted for these various condition classifications.

Interpretation of apparent trend depends on analysis of several data elements by comparison of the existing and potential plant communities and soils. These data elements include erosion, plant composition, ground cover, litter, age class, form class, plant vigor, and other indicators of trend.

Inherent productivity of the soil is another criteria used in determining suitability of the land for domestic grazing along with slope and erodability mentioned previously. Soil with a very low productive potential probably should not be grazed by domestic livestock for both economic and environmental reasons.

This has been a very brief enumeration of some of the most important data required in the Range Management program. For development of grazing management plans incorporating grazing systems such as rest-rotation, deferred, and

other systems; and for environmental assessment of the impacts of domestic grazing on other resources, much more basic inventory data is required for analysis and interpretation. Some additional data includes surface and underground water quantity and quality, meteorological information, cultural and visual resources and recreation uses, faunal inventory and terrestrial and aquatic habitat information, sediment yield, in addition to data on land status and ownership, geology, and mineral uses.

In closing, although the data required for wild horse and burro control, management, and protection is likewise quite extensive, a few data elements need emphasis. An estimate of the number of animals occupying various habitats, number of herds, migration patterns, seasonal use areas, is a continuing inventory need. For each herd, age classes and sex ratios are essential information for control and management of horses and burros. Manipulation of sex ratio and age structure will reduce the necessity for costly annual removal of excess animals. Theoretically, at least, annual increment will be equal to annual mortality by manipulation of age structure and sex ratios and, thus, excessive numbers will not accumulate.

Disintegrated Inventories of Natural Resources[1]

Jack Jacks[2], Dean Pennington[3], Lynn Kantner[3]

Abstract.--Mineral resource inventory is customarily avoided because it is expensive and time consuming. Mineral information inventory can serve a similiar purpose, but with little expense. This paper tells how to provide important minerals information to help guide use, development, and protection of other resources.

INTRODUCTION

Many thousands of inventories for mineral resources exist in university files, reports of State or Federal geological surveys, and in files of private organizations. These inventories vary from high altitude imagery interpretations for exploration targets to detailed subsurface summaries from drill hole information. Most are technically complicated and deal with a single mineral element or geologic condition of the earth. These are the "Disintegrated Inventories of Natural Resources."

This disintegrated minerals inventory information is valuable but not widely or wisely used to help make routine decisions about how, where, and why to use other natural resources. The reason for this is usually that decisionmakers seldom have the time and talent to successfully integrate this information into a usable form. The information is so abundant and complicated that it often looks like an impossible task. Unfortunately, it often is an impossible task.

This paper deals with an approach to integrating many of these mineral inventories into a single document.

WHAT KIND OF INVENTORY

Often resource managers or decisionmakers have ignored mineral resources because a complete evaluation of mineral potential required too much time and money. Managers think in terms of field mapping, diamond core holes, surface sampling, geophysical studies and work efforts from a host of highly skilled specialists. A minerals importance inventory requires none of these.

A minerals importance inventory requires only a single person with some technical talent for understanding minerals-geology publications. The person needs a week or two for information research, about twice as much time for interpretation reporting, and a copy of this paper.

A minerals importance inventory is different from the usual resource inventory in that it does not deal with finite counting or measuring. It deals with "information" inventory rather than "reserve" inventory and is based upon probability.

INFORMATION GATHERING

There is no intent to do an exhaustive job of gathering information (data). The intent is to do only the best job possible in the 1 or 2 weeks of time available.

The objective in this inventory phase is to develop a complete list of the mineral elements thought to occur locally and be of some economic importance to the subject area (based upon available information). This list should include those of past or current production and those which could be produced in the future.

The best place to begin the information search is the Geology and Minerals Branch of the State Department of Natural Resources. They will be able to provide most of the needed information and direct the investigator to other sources. These sources will usually

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[1]Presented at National Workshop on "Integrated Inventories of Renewable Natural Resources" (Sponsored by SAF and University of Arizona).

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include local offices of U. S. Bureau of Mines, U. S. Geological Survey, and private agencies or agents.

Some attempt should be made to establish a general ranking of the mineral elements in terms of their importance to economic and social welfare. At the same time, of course, the investigator should secure copies of geologic maps and other important reference materials.

INFORMATION INTERPRETATION

The objective of this part of the inventory work is to produce a map of the subject area which shows the geographic location of lands thought to have the highest and lowest importance for mineral resources.

"Importance" in this work is not national or State importance. Rather it is measured in terms of how important land areas are to the subject area, assuming that the subject area is to achieve its maximum mineral producing potential. The investigator should ask, "What part of the subject area is most important to maintain in a land use condition for mineral activities if the area is to take best advantage of its available mineral resources?"

The Minerals Importance Map is not intended to provide information about where to prospect. It is intended as a guide for helping to decide the best areas for developing other natural resources. It becomes a tool for a decision-maker to interject mineral-related information into the decisionmaking process.

Map construction is based upon the following criteria:

1. There must be at least three categories of "minerals importance."

2. Extreme dominance of any one category is not allowable.

3. If minimum of three categories is used, no categories may exceed 50 percent of the subject area and none may be less than 15 percent.

4. To the extent practical, there should be equal proportions of each category used. If the minimum of three categories is used, the most desirable map would be one where each is about 30 percent of the total area.

This criteria is arbitrary but provides a means to avoid the common situation in which the geologist tells the decisionmaker, "Minerals are important everywhere." This kind of information is of no special benefit when it comes to evaluation of alternatives for wilderness, outdoor recreation or watershed protection.

The technique for map construction is left to the investigator and requires a great deal of personal judgment. Two investigators, working independently with the same reference materials, would probably prepare slightly different maps. It is important to clearly document the technique used to do the work, because of the personal judgment involved. The technique (assumptions, priorities, weighting systems, etc.) should be well enough understood so that another investigator could apply them and produce a map very similiar to the original.

AN EXAMPLE

A fellow worker (Dean Pennington) has provided a special minerals interpretative map as an example of the process. The work can be done for both large and small areas. The confidence level for this interpretation is low since it was constructed in 4 hours.

This work varies from the standard approach in that it does not deal with <u>all</u> minerals in the subject area. The investigator decided to use only three mineral elements to determine energy importance areas (uranium, oil-gas, and coal). Additional elements, such as geothemal or peat, would have been considered if this was to be a more formal work product.

The data used here was personal knowledge of the investigator and a 1:2,500,000 scale geologic map covering the contiguous 48 states. Areas of major importance were delineated based upon subjective judgment of the investigator. Figures 1, 2, and 3 show these areas. In each Figure Type "A" areas are those with highest potential for production and "C" has the least.

URANIUM

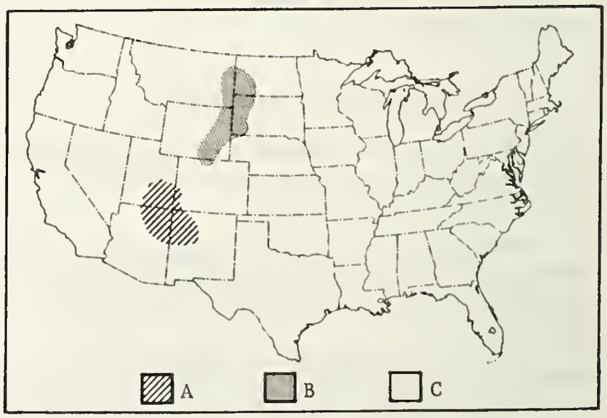

Figure 1

Figure 1 shows that land with uranium potential is of very limited geographic extent. The highest potential is in the Four Corners area (Utah, Colorado, New Mexico and Arizona).

OIL-GAS

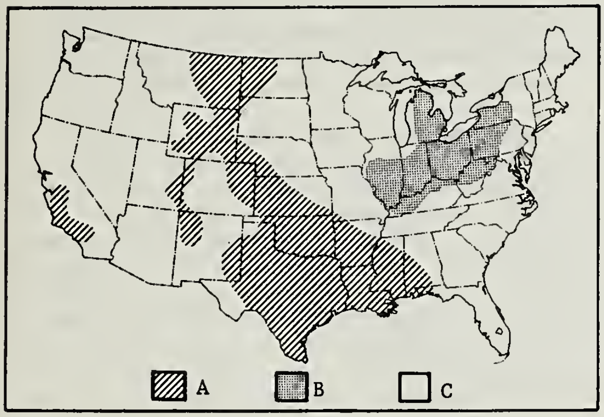

Figure 2

Figure 2 shows that oil-gas potential is wide spread with the highest potential in a band through central USA and an isolated area in California.

COAL

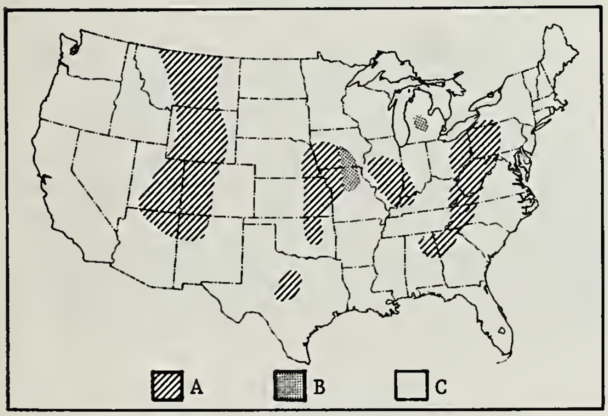

Figure 3

Figure 3 shows that highest potential for coal production is well distributed across the country.

Inspection of these three figures reveals that there is only a small area where Type "A" category exist for all three elements (Four Corners area). Deductive logic would suggest that this area is more important for energy resources than other areas. Further, one could conclude that areas where Type "A" value exist for both oil-gas and coal are more important than where there is only "A" value for either of these. This kind of deductive logic was followed in construction of the final map.

The first attempt at constructing a final composite Energy Importance Map resulted in a map (not shown) which had about 10 percent of the area in the "High" importance category and 50 percent in "Low." This map was derived by giving "High" rank to any area where there was a combination of "A" areas. Areas with single value of "A" or "B" were ranked as "Medium." This map did not meet the requirement that each category must exceed 15 percent of the total area.

The investigator was faced with the problem of which part of the area ranked as "Medium" to elevate to rank of "High" in order to achieve a 15-35-50 percent ratio. The technique used for this is not shown but followed a logically process of ranking and assigning numeric values to A, B, and C categories of the three elements used.

The final Energy Importance Map is shown in Figure 4. This Figure explains where one technical expert feels that energy minerals are most important in the original 48 states. In the final analysis parts of Illinois and Ohio-Pennsylvania were elevated to rank of "High."

ENERGY IMPORTANCE MAP

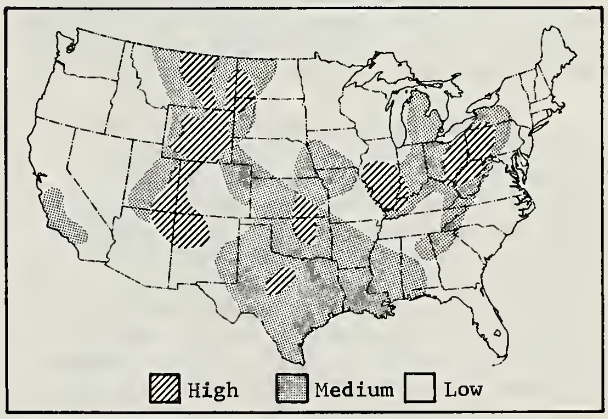

Figure 4

APPLICATIONS

This inventory technique has been applied to four National Forests in the Eastern Region on land areas ranging from 645,000 acres to 3 million acres. Forest geologists handle this kind of project in about 2 months. One project was contracted to a consulting geologist who provided the final map for 850,000 acres in a

period of 6 months (cost about $9,000).

The best application of the work is in developing long-range strategies about land use and being able to anticipate where to expect future activities from industry and private property owners. National Forest ownership in this Region is intermingled with private lands and does not always include the mineral estate.

Large capital investments are required for developed recreation, and it is of critical importance to know, for example, if strip mining might occur upstream of a proposed reservoir. Such interpretative maps may also provide a basis for making judgments about the best benefit/cost areas for land reclamation investments, or where to establish protection for wildlife habitat.

As a fictitious example, we might assume that Congress has identified a need to establish a 400,000 acre habit preserve for the endangered Rocky Mountain Gilapoo. Let's suppose that Idaho, Colorado, and Wyoming submitted nearly identical proposals. Wildlife preserves and energy production are not usually "compatible" land uses. If Congress wished to consider energy in making this decision, the "Example" map (Figure 4) would suggest funding the Idaho proposal over the others.

Minerals Importance Maps can help to make decisions about where to establish wilderness. They would be of special benefit in situations such as the "RARE II" study which is currently being conducted by the Forest Service.

Such maps can also be important for establishing a firm basis for decisions related to timber harvesting. Timber harvesting areas on National Forest System Lands are selected, in part, by referring to Minerals Importance Maps when they are available. Coincidence of important mineralized areas of high timber producing potential is considered to enhance land suitability for harvesting. This is because necessary transportation system for either will serve the other.

Foremost in applications is the capability of this kind of inventory product to help define, evaluate and choose alternatives related to land use and land management planning.

CONCLUSION

The two most important pursuits of man, in maintaining or elevating the quality of human life on this planet, are agriculture (including silviculture) and mining. Without food and basic raw materials for medicine, housing, clothing and energy, man could realize very little enjoyment from amenity resources such as outdoor recreation, scenery, wilderness, etc.

Wise decisions about natural resources depend upon adequate inventory which allows decisionmakers to understand the quality, quantity and geographic location of the resources. The basic resources of air, water and minerals (including soil) determine the quantity, quality and utility of other natural resources (such as timber, recreation, range, wildlife, fisheries, and visual). Yet decisionmakers rarely see inventories for air, water or minerals (excepting soil).

A minerals importance inventory approach, such as discussed here, can provide important information to decisionmakers in guiding the use, development and protection of other resources. At the same time it will help preserve the option for commodity land use in areas of high minerals importance, which will allow for the discovery of important mineral deposits.

A truly integrated inventory of natural resources should provide means to insure that the basic resources (air, water, minerals, and soil) receive consideration which equals or exceeds that provided for others. As a Forest Ranger once said, "Land use decisions made now and in the future must weigh all the resource, economic, and social factors involved. The decisions must be based on the best available and complete data. To do anything less than that is worse than making no decision at all (Al Elisar, Athens, Ohio 1977)."

LITERATURE CITED

Noted here are seven examples of work products prepared using this general technique. Original concepts were developed by Ray Wallace and others in response to information gathering and display for land management planning.

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Information Requirements for Timber Management: Just Part of an Integrated Information System[1]

Peter R. Russell[2]

Abstract.--Information requirements for timber management overlap with the requirements for log and tree allocation, log, tree and stand valuation, facility planning and measuring plant performance. Resource data can be integrated with log input/ product output relationships, market data, production and transportation costs to provide a "vertically" integrated data base for decision making.

Today I want to talk about information requirements for timber management, and four other related areas. The reason for speaking about a broader range of information requirements is that in an organization like International Paper Company we cannot isolate timber management as an activity unto itself. IP, as most of you know, manages timberland, operates wood products plants and manufactures and markets pulp and paper. All these activities require information and, while some of the information requirements are specific to certain aspects of the business, there are many areas where overlap occurs. It is this overlap of information requirements that forces us to take a broader view of where and how we are going to develop our management information.

This broader view immediately raises some questions: What are the information requirements for timber management, for log allocation, for facility planning, etc., and how do we collect, analyze and use this information? Well, the answer is, "We use integrated inventories to develop integrated information!"

Unfortunately, it is not quite that simple.

So, let's back up and, for the sake of mutual understanding, define integrated information; then talk about how IP develops, currently uses and plans to use integrated information in its Wood Products and Resources business.

On a theoretical level, there are at least two ways to integrate resource data. First, we can horizontally integrate data by conducting what I'll call a horizontally integrated resource inventory: A horizontally integrated inventory is, by this definition, a cataloging of natural resources. In other words, the horizontally integrated inventory must measure and define the different resource components in a stand or watershed or a whole eco-system. The horizontally integrated resource inventory includes measures of water, soil, plant life and wildlife.

A second type of integration is the vertical integration of resource data. By this I mean the integration of physical resource data with related non-resource data, with management objectives and with data processing systems.

These two definitions of horizontal and vertical integration are somewhat artificial but they do differentiate between two very different problems. On one hand the integration of different types of resource information and, on the other hand, the integration of resource data with non-resource data.

While both types of integration are important, we shall concentrate our discussion on vertically integrated information.

There are five major areas where vertically integrated resource information is required at International Paper Company:

1. Land Management
2. Log and Tree Allocation
3. Log, Tree and Stand Valuation
4. Facility Planning
5. Measuring Plant Performance

The data needs vary in each of these activities but there is tremendous overlap, and the challenge is not only to develop the information required but to take full advantage of it once we have collected it.

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[1]Paper presented at The Integrated Inventories of Renewable Natural Resources National Workshop at Tucson, Arizona, Jan. 8-12, 1978.

[2]Forest Resource Allocation Analyst, International Paper Company, Mobile, Alabama.

The challenge is there because in day-to-day operations there are many things we would like to do that we cannot do yet. I am not criticizing or making excuses, but quite often the realities of keeping a mill running after a month of rain overshadow things like integrated information systems.

We are working hard to develop an integrated information system that will provide data for different uses, but the reality is that we are not there yet, and it is certainly not a short or an inexpensive task to get there.

The cornerstone of an integrated information system is of course the resource data, and for this IP relies in the Northeast on a combination of broad-based continuous forest inventory and photo-stratified operational cruises. In the Northwest, on a stand description system and in the South, on our Forest Management Information System or FMIS. The FMIS system is designed to do three things. First, to obtain forest management data on a stand basis; second, to obtain timber volume estimates which are accurate within specified ranges; and third, to present the information in a format that is useful for each level of management. FMIS serves as a resource data base for Company lands in the South. It is a stand description system with sub-sampling, and from FMIS we get stand by stand, timberland, area and region volume summaries. We also get descriptions of timber location, accessibility, operability, age, site, stocking; and we obtain log stock tables by species, grade, diameter and length. This log stock table information is really the key link to the other information in the integrated system.

A second set of inputs to a vertically integrated information system is related non-resource data. This information is used in conjunction with the resource data to make management decisions. Non-resource data includes log input/product output relationships to estimate the volume and grade of the end products which can be produced from the resource. It includes market information in the form of log, lumber, plywood, chip and hog fuel prices for valuing these end products and it includes logging, production and transportation costs for completing the valuation process. Finally, the non-resource data should include any relevant physical, financial or operating constraints which affect management decisions.

Two other ingredients in the vertically integrated system are management objectives and a data processing system. While management objectives couldn't really be considered hard data, they are a vital input to the system, especially in the data interpretation stage. A data processing system is also vital, so it should be considered along with management objectives as a major component.

This all sounds very nice in theory, but what do we do now and what are we working toward in the five areas where vertically integrated information is required?

First is land management. IP has its forest inventory systems in place and on much of our land we are planting genetically improved stock and intensively managing the new plantations.

But, we need to track our progress and, among other things, analyze the financial alternatives of various stand management plans and harvest schedules, so, vertically integrated information is required: including basic resource data, transportation costs, market data, and information on the potential products contained in the standing inventory.

Thinning regime and rotation length analyses are continuing projects that make use of the data now, but we are also looking toward computer systems to schedule harvests by optimizing the net present value of groups of stands with a linear programming model.

IP has in the past used linear programming for harvest schedule planning and we are currently revamping and improving this system.

A second important use for vertically integrated information is in log and tree allocation. Our WOG, or Wood Order Guide, system is an LP model which generates least cost wood supply solutions for IP's paper mills. It is run quarterly to develop a shipping plan, and is also used by the planning group.

In addition to WOG we are now developing a computerized system which will help us determine the best allocation of logs by species, grade, diameter and length. The goal here is to allocate logs to facilities so that we optimize the total value of the harvest, not just the allocation to pulp mills. We want to get the pulpwood to the pulp mill; large sawlogs to the large log mill and small logs to the small log mill. In order to do this we need log stock information, log input/product output relationships for various facilities and current operating costs and sales data.

Log allocation solutions based on profit contribution are fairly simple once this data is available. Current prices are used to value potential products; then logging, manufacturing and transportation costs are subtracted and the allocation yielding the highest net value or profit contribution is the one to be favored.

The integrated information required for log allocation is similar to the data used in land management and also in log, tree and stand valuation, the third area where vertical integration is required. Good data is especially important for timber purchase and sale, so if potential products are valued, milling, logging and transportation costs are evaluated, then guidelines to stumpage bidding can be developed.

We currently use computer models for stumpage valuation, but a mill testing program has been instituted to expand our log input/product output data base so valuation techniques can be refined.

Facility planning is the fourth area where integration of data is important. Here the key variables are resource availability over time, market projections over time, and facility concepts for proposed processing plants. Once again, we need log stock tables for harvest volumes by species, grade, diameter and length. However, in a facility planning situation, the data must be projected into the future. I personally think the projection of grade over time is one of the major challenges to forest inventory today.

Our goal in facility planning is to match the facility to the available resource. But, once we have built our facility, decided which stands should be harvested, cut and allocated the logs to individual facilities, then it is time to ensure that the highest possible volume and value is recovered from this resource. So the fifth use of vertically integrated data is in measuring plant performance. IP is instituting a program where individual plants are measured for their performance against standards set for the type of raw material they are being supplied. In measuring plant performance we need detailed information on resource consumption; again, we need current market conditions and production costs, and with this information in hand a report can be developed showing the actual production and sales value for a shift; an estimated standard of performance based on the raw material and production variables, and a variance report showing the difference between actual performance and the projected standard.

Figure 1 is an outline of the system we've described. At the top you see the input coming in in the form of raw material data, our mill input/output relationships and our market and cost information.

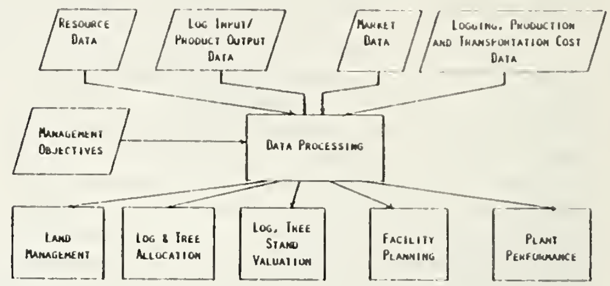

Figure 1.--A "Vertically" Integrated Information System

The data processing system is used to handle the inputs and provide data for use in land management; log and tree allocation; log, tree and stand valuation; facility planning and plant performance.

The complete impact of the system has not been fully felt at International Paper Company, but the importance of good raw material data, whether it comes from standing inventory or from measures of harvested volumes, just cannot be overstated. Nor can we treat this resource data as a self-contained block of information; it must be integrated with other non-resource information including log input/product output relationships, market information, and production and transportation costs. Then, with the help of a data processing system, the information must be interpreted in the light of management objectives.

Information Requirements for Wildlife Management[1]

L

L. Jack Lyon[2]

Abstract.--Wildlife is managed, directly and indirectly, by a great many different individuals and agencies. At all levels of management, information requirements appear to fall into two general categories: socio-political and biological. For many managers, the first category may represent the greater information void because there are few species for which clear management objectives have been defined. Biological information requirements range from basic resource inventories to specific census and habitat data and should include an ecologically sound strategy for management in the absence of data.

INTRODUCTION

Wildlife is managed, directly and indirectly, by a great many different individuals and agencies. Legal protection and hunting seasons are obvious manifestations of direct management while habitat manipulation is the common indirect management. The manipulation of habitat can defeat virtually any direct effort in protection. And, conversely, inadequate protection can defeat any attempt at habitat manipulation to favor wildlife.

Because protection of wildlife populations and their habitats are independent, management information is required at many different administrative levels. The greatest need may be among individuals or groups who do not recognize a need at all. It is a peculiar fact of wildlife management that the agencies charged with administrative responsibility may, in fact, have little direct control over the events that determine productivity in wildlife populations. Thus, before attempting to outline information requirements for wildlife management, it is necessary to briefly consider where the responsibility lies and who needs the information.

[1]Paper presented at a National Workshop; Integrated Inventories of Renewable Natural Resources, Tucson, AZ, Jan. 8-12, 1978.

[2]Wildlife Research Biologist, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

RESPONSIBILITY FOR WILDLIFE

"It is an American tradition, with legal substance, that wildlife is a public possession..." (Allen, 1954). As a public possession, or common property, wildlife has been subject to selective exploitation; with the result that a wide variety of legal and assumed levels of responsibility have developed as needs became apparent.

Game Species

Management of game animals has become a legal responsibility of the State Game Departments. Migratory species are managed under additional restrictions imposed by the Federal Government. Basically, however, these responsibilities are limited to protection from uncontrolled killing. For the agencies involved in this facet of wildlife management, information requirements would appear to be essentially biological. If the population status and breeding success are known, proposals for harvest rates and hunting season lengths can be based on sound information.

Anyone familiar with agency function, however, will recognize that biological information is only one of many factors involved. More often than not, socio-political views or information modify, or even supersede biological information. The public, and specifically the licensed sportsman, does have an interest in maintaining wildlife. The degree of commitment may vary from the habitat acquisition programs of Ducks Unlimited to local political pressure on a game commissioner. Thus, the manager requires both biological

information and some means of assessing public attitudes toward wildlife.

Nongame Species

Responsibility for management of nongame wildlife involves a number of uncertainties, especially related to financing. In 1975, Grieb and Graul reported that 30 States had nongame programs, but that only 17 had programs with at least one full-time nongame employee. These State programs are funded from hunting and fishing license fees, from general fund appropriations and from the sale of conservation stamps; but few can be considered well financed. Because of the limited funding available, most State and Federal programs have concentrated priorities on threatened and endangered species. Broader programs are being developed, but current nongame management is generally minimal. Lennartz and Bjugstad (1975) have suggested that information requirements for successful nongame programs include "... some consensus ... of what management ... should strive to achieve," assessment of the "... impacts of management systems on nongame ... and their habitats,", and information describing habitat selection of both species and communities.

In addition to these government-agency programs, nongame management is of considerable interest to the general public. If the figures cited by Payne and DeGraaf (1975) are correct, a very substantial voluntary investment by the public for feeding and watching small birds represents the single greatest share of assumed responsibility for nongame wildlife. Information requirements in this area may be almost impossible to define unless predicated on a description of the user group.

Habitat Management

Manipulation of wildlife habitat is typically the responsibility of the landowner or administrator who determines how land and vegetation are managed. The obligation to wildlife may be very uncertain. Actions taken by individual landowners may range from (1) direct, positive habitat manipulation on refuges and game ranges to (2) planned mitigation or positive action, perhaps under multiple-use management, through (3) no conscious consideration to (4) planned habitat destruction. Presumably, the two extreme actions are based on information adequate to accomplish the objectives. It is the multiple-use manager and the uninformed who require the most information because it is these levels at which inadvertent habitat manipulation is most likely to have unexpected adverse results for wildlife.

Responsibility

The responsibility for wildlife management, then, is both legal and assumed, broadly fragmented, and in some cases, not specifically assigned. Interest in wildlife and a concern for wildlife management is a public responsibility, but because the responsibility belongs to everyone, no one is specifically accountable. One of the characters created by cartoonist Walt Kelly paraphrased the situation perfectly. In the words of Pogo, "We have met the enemy and he is us." In this paper, I can attempt to describe information requirements for wildlife management, but my remarks are necessarily restricted to the obvious, legally responsible groups: professional wildlife biologists, administrators and land managers. While I recognize that a much larger audience exists, I can neither suggest a way to identify and reach that audience nor a way to successfully identify their information requirements.

NON-BIOLOGICAL INFORMATION

As a wildlife biologist, I consider it fairly obvious that several kinds of biological and behavioral information are necessary in wildlife management. This must be a widely held viewpoint, because the wildlife problem most often cited is a lack of adequate information. As a scientist whose main concern is the search for information, however, I'd like to propose some additional considerations. First, there is adequate evidence that information now available is not fully utilized--which suggests that dissemination as well as inadequacy of information is a serious problem. (In addition, some administrators simply are not interested in the information that is available.) Second, it is unrealistic to expect that adequate biological information for all wildlife species will ever become available. I cannot visualize a research budget that would produce population, life history and habitat information for the 400-800 game and nongame wildlife species found in most States. Neither can I visualize a totally satisfactory method for simplifying, sorting and storing such a volume of information so the manager could use it. And, finally, I suspect that even if adequate biological information were available, it could not be used because no one would know what to do with it.

This comment is not intended to be a cynical evaluation of the wildlife profession. In order to utilize information concerning wildlife, it is necessary to have wildlife management objectives. And despite good intentions, positive objectives in the United States.

were, until very recently, noticeable mostly by their absence.

It is true that some progress in establishing goals for wildlife management has been made. Over two decades ago, Durward Allen (1954) remarked about the lack of a "...national plan for resource use and development in which such things as fish, mammals, and birds take their proper place." During the last 10-15 years, many significant Federal and State actions have been taken to protect certain wildlife species or habitats (Jahn, 1977). At the national level, RPA[3] provides a partial planning vehicle; at the State level, the Sikes Act provides for some Federal-State coordination of objectives; and several States have developed "strategic plans" for wildlife. Nevertheless, these actions are in the developmental stages, and the normal format for decisions affecting wildlife involves either acceptance of existing habitat conditions and wildlife populations, defense against change, or planned mitigation of expected losses. None of these alternatives represents a positive commitment that the wildlife manager can use as a guide.

The essence of this problem lies in the fragmentation of responsibilities for wildlife. A State game department rarely specifies wildlife population goals for Federal or private lands; and conversely, the landowner or manager rarely sets harvest goals for the game department. Lennartz and Bjugstad (1975) have suggested that "...the professional, working in the public interest, ...take the lead in establishing management ...direction (because) ... we can't expect a clear public mandate...." While many professionals hold this view, it is also clear that such decisions constitute social-value rather than professional judgements. Another view holds that professionals should be responsible for describing reasonable management alternatives, including costs and alternatives, so that a public mandate can be obtained. While this has been done in a few instances a tremendous job remains.

The absence of a strong commitment to the status of wildlife and uncertainty in management direction has created a broad and perplexing gap in the information required for wildlife management. Within the commodity production format of a land management agency, the wildlife biologist is typically on the defensive and never very certain where wildlife fits into overall management planning. Unlike the boardfoot, animal-unit, or water-yield goals of other resource specialists, goals for the wildlife specialist are imprecise and unquantified. Lack of biological information is only half the problem. Even if specifications for doubling habitat productivity were available, there are no indications where to do it--or whether it should be done at all.

The problem is seemingly less acute for important game animals because the State Game Departments usually indicate "more" as a management objective[4]. However, until "how many more", "what kind", and "in which areas" are also specified; management decisions cannot be very adept. "More" is open ended. It tends to ignore other resource values as well. When applied to nongame wildlife, "more" is simply not a goal at all. The only exception seems to be our national declaration to restore endangered species and assure that no more are created. However, even this laudable goal suffers the defect that failure is our only obvious method of evaluation.

One of my reviewers pointed out that this gap in information also influences the way wildlife research is conducted and reported. It may be that wildlife biologists lack the sophistication to do otherwise,but it's apparent that most research is consequence oriented rather than goal oriented. Almost without exception, investigations of wildlife populations and habitats are designed to detect population change produced by some specific action rather than determining the action necessary to produce a desired population. Moreover, in presenting consequences, researchers often circumvent responsibility by asserting that selection of the appropriate action is a "management responsibility." Scientists defend that position on the assumption that the manager is the only one in possession of all the facts needed to make a decision. Nevertheless, it is worth considering that research results might be more useful if predicated on a clearly defined objective.

Finally, the subtle influence of management without objectives can be detected in the administrative function and professional standards applied to wildlife management. Paramount among these is the tendency for wildlife programs to be structured around activities rather than accomplishments. It is possible that our public land management agencies have no better method of assessing accomplishment than numbers of acres treated, numbers of fish structures

[3]National Assessment of Fish and Wildlife as required by the Forest and Range Lands Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976.

[4]Colorado's strategic plan lists 37 categories of wildlife. Only 6 are not programmed for increases in populations, harvests or hunter-days. Five of these 6 categories are nongame wildlife.

built or numbers of dollars spent in coordination and planning. It may be that numbers of licenses sold and numbers of animals killed is a valid measure of wildlife management success. It is even possible that adding up the number of pounds of bird seed, numbers of bird books and pairs of binoculars sold is a measure of success in nongame wildlife management. It is possible, but I doubt it. Professional accomplishment should be evaluated in the ability to utilize existing knowledge to produce predictable and desired results. If no one knows what the desired results are supposed to be, it is clearly not going to be possible to evaluate real accomplishment and determine accountability.

In summary, one of the singularly important requirements for wildlife management is definition of wildlife management objectives. In some situations, coordination between land management and game management agencies could result in joint management objectives. In others, a clear policy statement for an agency would help. However, Colorado's (1974) strategic plan recognizes situations in which action is needed from the U.S. Congress, from the State Legislature, from Federal agencies, from the Cattlemen and Woolgrowers, from Railroads, Irrigation Districts, County Commissioners, Municipalities, the Highway Department, Gas Companies, Conservation Organizations, Zoo's, private landowners and from the general public. Included in this array is a whole spectrum of political and social issues for which there appears to be no immediate resolution. Nevertheless, the problem is apparent. Forty-eight years ago, in a somewhat different context, Aldo Leopold (1930) concluded that, "Our whole situation demands a positive program ..." I agree.

BIOLOGICAL INFORMATION

The second broad category of information requirements for wildlife management includes the array of population, habitat and behavioral data already mentioned. The pressing need for such information is at least partially indicated by the number of nongame and habitat symposiums and workshops that have taken place in recent years. Last January, for example, many of you attended a National Symposium: Classification, Inventory, and Analysis of Fish and Wildlife Habitat.

Proceedings are not yet available, but that was a particularly significant meeting because it demonstrated some of the basic problems of processing information for wildlife management. In the introductory session, speakers pointed out that classification and inventory, in order to be widely useful, should satisfy several basic criteria. Data, for example, should be management oriented (Kusler). Data should be understandable, usable, and site specific (Baxter). Data should be technically and professionally credible (Davis and Henderson) and should be usable in a multiresource rather than a functional framework (Driscoll).

In the following technical sessions, speakers presented a series of papers indicating the myriad ways in which each management agency is inventing its own, specific approach to classification and inventory. I detected none of the underlying consistency called for by the introductory speakers. Indeed, considering the numbers of different people, different agencies, different information needs--and the incredible number of wildlife species for which at least basic information is needed--consistency would be unexpected. It probably isn't possible, and I suspect it might not even be desirable. There are, however, two related areas of concern that should receive consideration.

First, it is important that a lack of consistency and coordination not degenerate into the NIH Syndrome (Not Invented Here). It is true that all studies of biological phenomena have limits of extrapolation. It is rare indeed when these limits of extrapolation happen to coincide with State boundaries or the political subdivisions of agency responsibility. Despite a widespread proclivity to believe otherwise, it is not really necessary that biological information required for wildlife management be independently discovered within each State and by each agency within the State.

Second, it is important that the effort put into obtaining information be scaled to the level of precision indicated by management objectives and the way the information will be used. Information is expensive. When the information collected is not of the right kind, or is not properly or fully utilized, both time and money are wasted. It is not adequate to list a variety of useful biological parameters --as I am about to do. Each parameter must be evaluated in terms of the management purpose it is intended to fulfill and the management level at which it will be used.

Biological Parameters

In a broad sense, there is probably no limit to the amount of biological information needed for wildlife management. No competent manager in any field is ever truly satisfied with the information available to him. The more precise the management objective, the more information is required. And yet,

decisions are made on the basis of available information--no matter how inadequate. In the present state of the art, it is apparent that one further kind of information is required: some logical and basic rationale for wildlife management in the absence of data. The following discussion of biological parameters, then, includes population, habitat and behavioral information as basic hard data requirements--and a fourth category of rational alternatives when no information is available.

Population Information

Census, of some kind, is certainly the basic biological parameter of wildlife management. As a research biologist, I've often thought that an accurate, instantaneous, repeatable census technique would solve most wildlife management problems. Unfortunately, I know of no census technique for any species that even approaches these criteria. Instead, managers settle for annual trend information based on aerial or roadside counts, manipulation of demographic data or even a kind of "best estimate" based on range or habitat condition. It is not the purpose of this paper to evaluate the quality of this information, but several recent papers have suggested that it isn't very good--even for the large and important game species. Despite a 50 percent decline in mule deer harvests over the past 15 years (Julander and Low, 1976; Urness, 1976; Tueller, 1976; Denney, 1976; Knowlton, 1976), Gill (1976) has suggested that "...the great mule deer decline is a myth..." and Wolfe (1976) and Pengelly (1976) imply that we would be unable to accurately detect such a population change if it did occur.

The need for accurate census information is high, the probability of obtaining such information quite low, and there appears to be no immediate solution to the problem. Wolfe (1976) cautioned that "...management agencies ...avoid reliance on a single method or informational input..." to assess population trends. To this good advice, I would add a caution against using population trends as the sole input for wildlife management.

Some wildlife management objectives can be met with population data alone, but population information has a deceptive and very serious limitation. As Allen (1977) has pointed out, "...most of our management efforts have been spent responding to existing population parameters, at the same time attempting to insure that habitat was <u>not</u> altered." Population information is best suited to neutral or negative management goals, and if used as the sole information source may siphon away resources that could be better utilized in other ways.

Habitat Information

In meeting positive wildlife management goals, it is often far more productive to obtain information about existing habitat and the potential for modification than to determine wildlife population densities. Information requirements for wildlife habitat manipulation are usually determined by the underlying philosophy applicable to the situation. For many years, wildlife managers have used "...the concept of limiting factors" (Leopold, 1948) as a guide to management action. If food, cover, or water is limiting, management prescription is based on correction of the deficiency. More recently, we have seen the development of a holistic approach using "optimum habitat" (Black, et. al, 1976) as a habitat manipulation goal.

Either approach requires at least some information about the existing habitat and why it is used by wildlife. Managers would like to know which factors of environment are limiting or, alternatively, what amounts and arrangements of food, cover, and water will result in the "...greatest possible use of the greatest area..." (Black, et al, 1976). Again, however, our current ability to obtain such information falls far short of the requirements when serious, positive wildlife management objectives have been established.

Allen (1977) has suggested that successful habitat management requires several assumptions:

1. That we know where an animal lives, yearlong and seasonally;
2. That we know why it lives there, recognizing the difference between "necessities" and "fringe benefits";
3. That we understand how, when and for how long specific habitat alterations influence the necessities; and,
4. That we know the potential of the wildlife resource for human use and that we are aware of how various land use alternatives influence our wildlife management objectives.

Obviously, there are few species for which this information is available at the level of precision managers would like to have. On the other hand, Thomas, et al (1975), Black, et al (1976) and others have shown that it is possible to formulate existing publications, knowledge and best estimates into workable guidelines for habitat management. The main ingredients in developing such guidelines appear to be recognition that while (1) "... there is not the quantity and quality of data on every vertebrate species that we would like, yet we do have sufficient knowledge to make a good start" (Thomas, et al, 1976), (2) if we wait until all the facts are in, it will be too late because habitat is constantly being modified whether wildlife is considered or not, and (3) initial guidelines should be revised and improved through continuous follow-up evaluation.

Behavioral Information

The third category of biological information requirements represents, in part, a growing recognition that wildlife responses to an available environment may be something more than physiological. Dice (1952:338) observes that "...each kind of organism ultimately reaches every local habitat suitable for its existence unless prevented by a barrier of some kind," but Beament (1961) has noted that nearly all animals are physiologically capable of surviving over a broader environmental range than they actually occupy. Barriers to habitat occupation may be behavioral rather than physical, and, if so, the information required for habitat management takes on a slightly different perspective. Allen (1977) has concluded that in addition to knowing where animals are and what they are doing, we need to know "...why animals do some of the things they do."

For immediate application in wildlife management, two general kinds of behavioral information seem particularly important. One kind applies to the ways animals respond to their environment--in essence, Allen's "why?". As an example, consider Beall's (1976) observations on elk behavior in response to thermal radiation. The pattern of selection for elk bedding sites on winter range appeared almost random until Beall showed that animals were actively seeking specific microenvironments in response to changing conditions of thermal and solar radiation. These responses may actually have been physiological, but it was the behavioral aspect of the study that produced useful guidelines for habitat management on winter ranges.

The second kind of behavioral information required is an ability to predict the response of wildlife to management actions and disturbances in the habitat. Geist (1971) has pointed out that disturbances by humans

> ...can cause severe alterations to the behavior of a species with repercussions on the physiology, population dynamics, and ecology of the animals.

This particular aspect of wildlife behavior seems most important for large ungulates--possibly because big game, elk in particular, have received the most attention. It does appear significant that a very large proportion of the recent literature concerning elk has reported animal behavior in relation to roads and logging. Comparable disturbances in the habitats of other wildlife species may be less significant, but we really don't know that. "On this subject we must become much better informed so as to protect faunas from apparently innocent human actions" (Geist, 1971).

Rational Alternatives

For the majority of wildlife species, and particularly for a large number of nongame species, usable management information of any kind appears to be nonexistent. Reduction of a population to threatened or endangered status will usually draw enough attention, and money, to initiate collection of information; but this is not considered an acceptable form of management. As an alternative, the manager requires some kind of rational approach to wildlife which, even if it provides no basis for positive management, at least increases the probability that no additional endangered species will be created.

The obvious answer to this problem is to protect existing wildlife and prevent alteration of the habitat. It is just as obvious that this answer is neither reasonable nor possible. However, at least one alternative that appears to be both reasonable and possible has been suggested for the Blue Mountains of Oregon and Washington (Thomas, et al, 1976). In that area, 379 vertebrate species are known to occur. Each of these species can be associated with one or more plant communities or successional stages.

> The fewer successional stages and plant communities used, the less adaptable and more vulnerable the species to habitat manipulation. Conversely, the more stages and communities used, the more adaptable and less vulnerable the species (p. 458).

The underlying rationale is direct and obvious: management in the absence of information can be based on creation or maintenance of habitat diversity. If all plant communities and successional stages are adequately represented, dependent wildlife species will also be represented. Habitats of the less adaptable and more vulnerable species should receive special attention, and additional information is needed for "...promoting the welfare and numbers of a particular species" (Thomas, et al, 1976:458).

SUMMARY

Wildlife is managed, directly and indirectly, by a great many different individuals and agencies. As a result, information for wildlife management is required at many different levels. At all levels of management, information requirements appear to fall into two general categories: socio-political and biological.

In the socio-political category, the greatest information need appears to be a definition of status for wildlife and the establishment of meaningful goals in wildlife management. As long as the wildlife manager continues to deal with obscure and unquantified management objectives, benefits to wildlife and evaluation of accomplishment will also remain obscure and unquantified.

In the biological category there is probably no limit to the amount of information managers would like to have; and as the level of management precision increases, the quality and quantity of information required also increases. At all but the least precise levels of management, some combination of population, habitat and behavioral information is required. When adequate information is not available the manager can at least assure that habitat diversity is maintained.

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Soil Surveys — the Basis for Management[1]

Douglas S. Pease[2]

Abstract.--A soil survey is a field investigation. It consists of a soil map showing the geographic distributiin of different kinds of soil and an accompanying text that describes, defines, classifies, and interprets for use, the different kinds of soil. Soil surveys are made to collect soil information that is useful in developing soil management systems, and evaluating and predicting effects of continuing or changing land uses.

INTRODUCTION

Many people assume that soils are much alike. They are not aware that large differences in soil properties can occur within short distances.

What is a soil survey? What is its purpose? How is it made? Who does it? Who uses it? The answers to these questions will be useful to people interested in improving the productivity of the land and retaining or improving the quality of the environment.

Soil, in the general sense, covers most of the land surface of the earth. More specifically soil is the collection of natural bodies on the earth's surface containing living matter and supporting or capable of supporting plants out-of-doors (Soil Survey Staff 1975). Soil is three dimensional. It is bounded on the surface by air or shallow water. Its margins grade to deep water, rock, or ice. Its lower limit is hard rock or earthy material nearly devoid of roots, animals, or other biological activity. Thus soil has area, shape, and depth (Kellogg 1961).

An understanding of soil properties and their effects under alternative use and management systems is a prerequisite to sound land use planning and management. A soil survey can help us use the soil resources without damaging it.

SOIL SURVEYS

To make a modern soil survey the soil scientist uses as a base map, a set of aerial photographs covering the geographic area he is going to map. He uses field methods to identify, describe, and classify the different soils in an area and to delineate the areas they occupy. A soil map shows the geographic distribution of different kinds of soil. (Soil Survey Staff 1951).

The fundamental purpose of a soil survey is to make predictions. The many different kinds of soils have unlike management or construction requirements for economic, sustained production or use.

Orders of Soil Surveys

Different intensities of field study, different degrees of detail in mapping, different kinds of mapping unit components and different mapping unit designs produce soil surveys of widely ranging applicability for problem solving. The basic elements of making a soil survey can be adjusted to provide the most useful soil survey for the intended purposes. These purposes need to be identified and defined. Soil scientists and specialists in other fields help to define the purposes of the survey, design the mapping units, and prepare the interpretations and test their validity.

The order or intensity of the soil survey is designed to meet the needs of the primary users. The degree of detail should be commensurate with the anticipated level of planning and management. I will give some examples of the orders of soil surveys:

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The Soils of the University of Arizona Experiment Station: Safford (Post, Hendricks, and Hart 1977) is a detailed soil survey mapped as a 1st order survey. The soil map is published at a scale of 1:4,224 (15 inches per mile) on an aerial photograph base map. The report contains detailed information suitable for managing research plots.

The Soil Survey of Susquehanna County, Pennsylvania (Reber 1973) is representative of a detailed soil survey or what we refer to as a 2nd order survey. The soil maps are published at a scale of 1:20,000 (3.168 inches per mile) on an aerial photograph base map. The published soil survey contains detailed information that can be applied in managing and planning farms and woodland; in selecting sites for roads, ponds, buildings, and other structures; and in judging the suitability of tracts of land for farming, forestry, industry, and recreation.

The Soil Survey of White Sands Missle Range, New Mexico (Neher and Bailey 1976) is a less detailed soil survey. We refer to this as a 3rd order survey. The soil maps are published at a scale of 1:100,000 (0.63 inches per mile) on line maps. The publication contains detailed information that can be applied in managing military lands. It also contains information that can be used in broad planning for grazing land, recreation, and wildlife.

The General Soil Map of Pima County, Arizona (Richardson and Miller 1974) is a generalized soil survey. It has about the same detail as a 4th order survey. The soil map is published at a scale of 1:500,000 (about 8 miles per inch). The report contains general information that is useful for general planning only and is not suitable for detailed planning.

The Alaska exploratory soil survey is an example of a 5th order survey. The survey was based on field procedures. A soil survey such as this contains information that is useful for broad regional planning.

The different kinds of soil surveys require maps with different scales and different levels of descriptions and interpretations to meet the needs for its intended use.

The standards of purity of the mapping units are adjusted according to the precision needed for the purposes of the soil survey. Delineations of mapping units in all levels of soil surveys usually contain some kinds of soils that are not identified in their names. These are mapping inclusions. In mapping, effort is made to keep delineations of the same mapping unit as pure as possible for the purposes it is to serve. It is not intended that a soil map will eliminate the need for on-site investigations for specific engineering structures.

SOIL PROPERTIES

Soil forms through the physical and chemical weathering of deposited or accumulated geologic material. Five factors of soil formation determine the properties of a soil.

The physical and mineralogical composition of the parent material affects the kind of soil that can be formed. Climate and plant and animal life act on the parent material that has accumulated through the weathering of rocks and slowly change it into a natural body that has genetically related horizons. Relief, or the lay of the land, conditions the effects of climate and vegetation on the parent material. Finally, time is needed for the formation of distinct soil horizons.

The classification of soils and the validity of soil interpretations are based on the fact that soils have specific properties that can be recognized and described. What are these soil properties? Some of the properties that are commonly observed or measured by a soil scientist are:

1. Color
2. Texture
3. Coarse fragments, including gravel, cobbles, and stones
4. Structure
5. Consistence
6. Reaction - acidity or alkalinity
7. Presence of carbonates and salts
8. Clay films
9. Flooding
10. Slope
11. Depth to soft rock, hard rock, or a pan
12. Drainage
13. Depth to water table
14. Soil moisture and temperature

The soil scientist studies these soil properties and their interactions. It is important to distinguish clearly between soil properties and soil qualities. Soil properties are relatively permanent but soil qualities are subject to change. Soil fertility, productivity, hydrology, and sedimentation are examples of soil qualities. They can change as modern techniques of management are applied.

SOIL SURVEY INTERPRETATIONS

Soil surveys are made to help people select

soils that are suitable for a particular use, choose uses for soils they may have on a tract of land, or design management systems and corrective measures needed for good performance of soils. Soil surveys must be interpreted for such decisions.

Soil survey interpretations predict potentials, limitations, and management needs for use of different soils. These interpretations are not recommendations for specific woodlands, farms, fields, or other tracts of land. Rather, they are one of the many inputs needed in developing good land use decisions.

Good land use depends on many factors. The kind of soil, the pattern of associated soils, location in relation to markets and services, the skill of the operator, and the availability of credit, water, and energy are all factors to be considered.

The information for soil interpretations comes from the results of research and the experience of users on individual soils.

Soil maps that are accurately made can be reinterpreted easily with little field work where there have been changes in management practices (Kellogg 1959). Thus a soil survey based on soil properties adequately described and classified is a survey that can be interpreted and reinterpreted in an orderly way.

As mentioned before, the kinds of soils classified are not shown with the same degree of cartographic detail in all areas. A soil map detailed enough and accurate enough for planning will likely serve a great many other purposes.

The purpose of soil classification and correlation is to give predictions through the use of soil maps. Using the interpretations helps us test the classification. The transfer of proven technology from known kinds of soil at one location to the same soil or similar soils at other locations is an important use of soil surveys.

Soil survey interpretations provide users of soil surveys with predictions about the behavior of each kind of soil under defined conditions. Interpretations of the soils indicate the reasonable alternatives for their use and management and their expected results.

SUMMARY

A published soil survey consists of a soil map and text that describes the kinds of soil and gives soil interpretations for a geographic area.

The degree of detail of a soil survey can be adjusted to meet the needs of the users. Soils are classified according to their soil properties. A properly designed soil survey can be reinterpreted when management and technology change. The soil interpretations give predictions of how a soil will respond under a specific use.

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Surveys for Forest Resource Demand Analysis[1]

Robert N. Stone and Thomas C. Marcin[2]

Abstract.--Resource use surveys for timber products and recreation are contrasts with Natural resource inventories in presenting the objectives and characteristics of surveys of resource use. A conceptual model of a wood consumption statistical system illustrates the range of timber use surveys. Aspects of projecting resource demand are discussed.

INTRODUCTION

What comes to mind when one contemplates a natural resource inventory is a project designed to estimate the current quantities of some resources of interest. Most often, forest inventories are made to estimate--within some geographic sampling frame--the amount of forest area, timber volume, and timber growth. This has been the traditional objective of the National Forest inventory where emphasis is on estimating current means and totals. Ware (1977) and others have questioned the usefulness of such inventories for analytical purposes and have developed broader objectives. Ware suggests the ideal inventory system should provide not just a prediction of change but must make possible the "explanation of changes that have taken place in response to inputs...." In short, we should measure to gain insight, not numbers.

The economic coin has two sides--supply and demand. As with resource supply, information about resource demands, and past changes and anticipated changes in demands, is essential for policy formation and program planning.

Measures of forest resource use are an important part of natural resource information and planning systems, and resource inventories should be made to either provide information for resource planning or develop new scientific information. Resource management decisions always are based upon some set of assumptions about future resource demands and environmental impacts. For example, in the introduction to this program we are presented with this assumption about demand:

> "As the world population increases, the demand for our natural resources will also increase. It is imperative that we develop efficient, objective methods of determining the resources we have."

Timely estimates of current and prospective uses of our resources serve another purpose. A resource value is largely determined by how our society uses it. Use is an index of society's priorities which ultimately should guide the resource manager.

Resource use may take many forms which can be classified into noncommodity and commodity uses.

Noncommodity uses are generally related to physical or aesthetic presence on the land, such as recreation activities or the use of land as natural preserve for some species of flora or fauna. These uses take place at the site.

For our definition, commodity uses are products which can be severed from the land and shipped and used anywhere. For example, timber products, minerals, fur, forage, and livestock are commodities. For most commodities, final use is away from the source.

An example of noncommodity land use is recreation. Surveys of recreation use may be classified as follows: (1) Site-specific surveys of recreation areas, (2) site-specific user interviews, and (3) household-specific surveys of the total population. A census of

[1] Presented at the Society of American Foresters' National Workshop on Integrated Inventories of Renewable Natural Resources Tucson, Arizona, January 9, 1978.

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aggregate use of a specific site can be conducted by simply counting individuals or fees.

Data on recreation use by age and social classes collected in these surveys will enable resource managers to anticipate and plan for future levels of recreation activity. Specific information about population characteristics relative to recreation use will help determine how we should manage and plan for inventories of recreation resources.

Wood products are an important commodity resource use. Most wood products are used far from forest land. They may be shipped anywhere, to national and international markets. In addition, wood products use is usually intermediate in the production of a final product--such as a house.

A CONCEPTUAL FRAMEWORK FOR WOOD USE SURVEYS

Since there are many end uses for wood products, many different sampling techniques are required. There are also numerous points in the production system from stump to final use where we may sample.

In determining wood products use, we can sample at various points in the production process from intermediate commodities (such as lumber, plywood, and board products) to finished goods such as furniture products. Most often we don't need to sample at the intermediate processing stage as substantial data are collected by various trade associations. However, we must have links between measures of business activity and these measures of industrial output. The purpose of wood products end-use surveys is to provide these links.

A conceptual U.S. wood products consumption system is summarized in figure 1. The system includes four sectors or levels of activities. Requirements for wood products become visible first as felled timber or timber cut. When summed across a specific year, the quantities are also referred to as timber removals. The quantities are usually defined in such units as board feet, cords, cubic feet, or cunits. Descriptive variables include species, tree size, location, and tree class. Statistics about timber cut or removals for states, regions, and the country are the responsibility of the Forest Survey units. Normally, timber-cut statistics are gathered during state-by-state forest surveys when the primary focus is on forest area, timber volume, and growth statistics.

The second level is isolated as timber products output. These are the first definable products. Examples are fence posts, sawlogs, and pulpwood. These statistics are also gathered by the Forest Survey on a variety of cycles. Independent estimates of pulpwood are gathered by industrial associations and the Bureau of Census.

The next sector, timber commodities, are generally processed in a mill and include lumber, plywood, woodpulp, and several other products. Statistics on selected timber commodities are gathered by the U.S. Forest Service, Bureau of Census, and many industry associations. The current Industrial Statistics of the Bureau of Census annually presents lumber, plywood, particleboard, and woodpulp production estimates. Most industry associations compile production data--some of which is very detailed. Unfortunately, much vital data compiled by industry is never made public.

The fourth level is the market or end-use sector. This sector includes categories such as housing, construction, manufacturing, exports, transportation, and agriculture. Numerous groups have statistics on certain parts of this sector. Some are the Bureau of Labor, Bureau of Census, Bureau of Economic Analysis, National Home Builders, and Census of Agriculture.

Surveys of end-use markets for wood products are a good example of the complexity of determining the final use of a multiproduct commodity resource. In general, surveys are easiest to conduct at the point of manufacture or construction of the final product. For some uses or activities, however, we must sample from all households in the nation.

SURVEY METHODS

The most important types of surveys are for the determination of wood use in construction which accounts for about one-half of wood products use. Much of this is in residential construction. These surveys are usually conducted by either sampling from building permits and then examining the construction drawings or by sampling the universe of builders or contractors (Reid 1977). The unit of sample is typically wood use per square foot of building or wood use per dollar of expenditure. A more neglected problem is the determination of wood use in repair and remodeling of residential buildings. In general, we don't know whether to sample households or contractors for this type of information. In addition, it is difficult for homeowners or builders to recall exactly what materials were used. Another type of sample is the canvass of all manufacturers of a particular product or group of products

errors and randomize those arising from differences in interviewers, time and sample, order of question, or other factors which could bias the results.

The problem of nonrespondents is a major problem which is not encountered in most resource surveys where a physical quantity is measured by specialists. With surveys which require a positive response there is usually part of the population for which no measurement is obtained. If this nonresponse is sizeable, then the study results may be biased and no statistical confidence limits can be assigned to them.

The detection and measurement of non-coverage are difficult. Comparison between surveys which cover the same population or give similar results is one check. One alternative is to stratify the sample by certain characteristics such as age, income, or geographic location, and to select a specific number of individuals in each class and assume that they approximate the general population. Another alternative is to establish a specific number of callbacks or of remailings before giving up. In the case of mail surveys, telephone contact or personal interview might be attempted before giving up.

After the first attempts to reach the sample units by a mail questionnaire, another approach is to take a random subsample nonrespondent and to determine if there is any statistically significant difference. If significant differences are encountered, then sample results can be adjusted to reduce expected sampling error.

Errors resulting from factors other than random sampling can cause estimates to be biased. These biases vary from item to item and survey to survey. While solution of these problems is difficult, it is important to acknowledge their existence. A long-term goal of surveys of end-use is to establish methods and procedures in which sampling error limits can be stated.

Chappelle (1972) has written about an aspect of measurement pertinent to some of these approaches:

When we look to the human side of natural resources, things become even less quantitative in the measurement sense of the word. The human side is concerned predominantly with owners and users of natural resources. Here we may be concerned with such items as: (1) age of the user or owner, (2) occupation of the user or owner, (3) ethnic and national origin of the user or owner, (4) type of business (corporate, partnership, etc.), (5) location of the business relative to suppliers and customers, (6) race of the user or owners, and (7) attitudes of operators regarding resource conservation, use, and development.

There are some definite measurement problems associated with these types of data. These data items range from very impersonal to very personal characteristics of owners and users. This means that we may expect a variable degree of resistance from the respondent when he is surveyed.

This interest in the performers is not unique to the demand side. Those conducting forest resource surveys are aware of growing pressure to learn more about the landowner and manager. Interest is especially keen about the intentions of the private non-industrial forest owner, for example.

PROJECTION

One purpose of projections is to identify future resource requirements for the formulation of management policy and programs.

Survey data should be related to economic, social, and demographic determinants of resource use for making projections. In the wood products consumption system, determinants of use are usually related to the following economic series of construction or business activity collected by the government.

(1) New housing units started
(2) Mobile home shipments
(3) Expenditures for nonresidential construction
(4) Expenditures for residential repair and alteration
(5) The value of manufactured products shipped

These are the major national statistical series used to project wood products consumption. These series are then linked to determinants of long-run determinates consumption such as gross national product and population.

Noncommodity uses of forest and other wild lands usually do not have market price or other economic data series associated with them. Recreation use has a large body of data on attendance and fees paid at specific sites; however, it does not have a general market where the price of recreation use is determined. In addition, many recreational uses such as bird watching or hiking also take place outside of designated recreational sites. General surveys of recreation participation for the total U.S. population

have been conducted by the Bureau of Outdoor Recreation and can be utilized for projection purposes (Marcin and Lime 1977). However, we do not have specific economic series to link projection of recreation use to other than total population by age group.

Other noncommodity uses are even more difficult to project because we lack basic measurements of use and often don't know how to value them. The best we can hope to do with projecting most noncommodity resource uses other than recreation and game hunting is to catalog them and to estimate the impact of other uses on them -- for example, maintaining a diversity of wildlife species.

Projection generally means a logical extension of past levels of use based upon a set of historical and starting assumptions about demographic, social, and economic variables. (In contrast, forecasts are avowed attempts to foretell the future.) It is the logic of the assumptions which normally determines the end results of projection.

It is important to distinguish between short-term and long-term projections, because many economic variables which are important in inventory and business cycles are not important in time periods of 5 years or more. In the very long run, population and the level of economic activity are the main variables in determining resource use. In addition, technological and social change are major influences but generally unquantifiable factors which influence use (Fisher 1963). Rather than completely ignore technological change it should be taken into account wherever such change is reasonably possible or foreseeable. Many changes in technology are parts of ongoing trends already incorporated into data. In this case, technological change is already accounted for. It is when the trend stops or changes that we must adjust our projections. For example, many technological changes of the last 30 years, brought about in part by declining relative fuel prices, will be altered.

Other changes are even more difficult to project. However, we can study past patterns of living and extrapolate trends in the future. For example, in recreation we know that participation in certain types of recreational activities in childhood will influence participation in these activities in adulthood. In addition, we can assess trends to a better educated, more affluent society by studying reaction activity relative to these social-economic characteristics.

Perhaps the most important variable in long range projection is the size and age structure of the population. Consumption of many products depends primarily upon size of the population. Others, such as schools, depend upon the number of persons in particular age groups. For example, the current surplus of elementary schools and teachers was foreseeable 10 years ago because of declining births. Better planning could have avoided some of the current problems of oversupply. The size and age composition of the population are a major determinant of the number of households, which largely determines the market for new houses, furniture, automobiles, etc. The age and sex composition of the population also are the major determinate of the size of the labor force which is, in turn, a principal determinate of the total output of the economy or Gross National Product (GNP). In the long run, the level of GNP and the closely related indicator, Personal Disposal Income (PDI), are the major referral series for the consumption of many commodities such as wood products.

Income per person is the major indicator of social affluence. In the wood products consumption system, we generally attempt to relate time series for construction and manufacturing activities to GNP or PDI and population.

Surveys of wood-use for each of these types of activities are then incorporated into a system for estimating coefficients of use for various types of wood products such as lumber, plywood, and other panel products. The final result is a set of projections of wood product requirements which can be then incorporated into a system to relate wood product consumption into estimates of timber supply requirements.

Projection is not the direct concern of every multiproduct survey. But, it is important to consider how survey data might fit into a general information or modeling system when designing surveys.

Often a little additional information on the characteristics of users or the relationship of an end use to socio-economic variables such as price, travel distance, or distance to markets, can be extremely beneficial in use of the data later. Analysis of present and prosepective resource use should be an integral part of any resource planning inventory.

DISCUSSIONS AND CONCLUSIONS

We have attempted above to sketch briefly the objectives and characteristics of surveys of resource use with particular emphasis on timber products use studies. As with resource inventories, we want to learn from these studies

WOOD CONSUMPTION STATISTICS SYSTEM

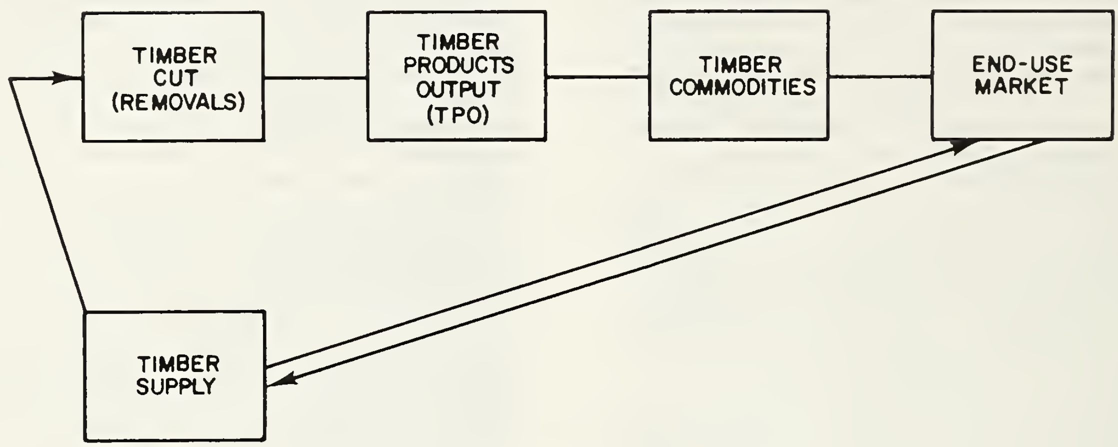

Figure 1.--Components of a wood consumption statistics system

(Dickerhoof 1977). Here the sampling is from a listing of manufacturing establishments.

Common to all these types of different sampling universes are certain general types of survey methods. They may be summarized as:

(1) Direct examination of the object of survey or of its plans or records of material use.

(2) Mail questionnaire surveys of individuals or business organizations.

(3) Personal interviews of heads of households or businesses.

(4) Telephone interviews of heads of households or businesses.

(5) Interviews with panels of individuals who are repeatedly sampled.

(6) Interviews with selected experts in a particular business.

In complex surveys which involve sampling human or business populations, we are faced with sources of error in addition to the normal error from random sampling variation, assuming a proper statistical design. First, there is the problem of nonrespondents; i.e., the failure to locate some individuals or their refusal to answer the questions when located. Second, there are errors of measurement or of interpretation of questions. With human populations, the respondents may not possess accurate information; they may give biased answers, or they may interpret the question in an unintended way.

Errors of measurements in surveys of human population are often difficult to detect and correct. The design of the questionnaire and the training of interviewers are particularly important.

An important procedure in reducing errors of measure is to pilot test the questionnaire on a small sample before conducting the main survey. There is also the problem of changed response in the case of household panels where surveys are repeated. Sometimes later responses are not independent from the first interview as households "learn" the questionnaire procedure or develop better recall. Poorly trained interviewers may result in biased, incomplete, or inaccurate measurement. A number of mathematical models have been developed to investigate errors of measurement (Cochran 1963). Generally, the best we can hope to do is to eliminate obvious

the current situation, how it is changing, and why. We want to relate use to available economic parameters as a basis for projecting potential uses under specific sets of assumptions about the future. We also want to know about the users and how they may be changing in number and intentions. Intentions are related to income and educational levels. The goal is to gain insights in the patterns of change to permit projections of timber requirements, and thereby the adequacy of projected resource supplies.

Differences exist in studies of resource use when contrasted to resource inventories, but many similar or parallel concerns are apparent. The steps involved in defining the population, designing the sample, collecting data, keypunching and verifying, editing, calculating additional variables, computing means and totals, estimating sampling errors, analyzing and reporting results, and projecting trends have much in common for resource use and resource inventories.

Among the differences, resources have a fixed location but materials, products, and services are transported from the original location during the various levels of production and even in end uses.

In resource surveys, the investigator most often measures or has measured variables of interest. In use surveys, this is difficult or prohibitively expensive so estimates are often obtained. Tally sheets give way to questionnaires and problems from misinterpreting mistakes and indifferences multiply. Nonrespondents must be planned for and the effects carefully dealt with.

We have presented the other side of the coin--the estimation of resource use or demand. Resource inventories are essential to define what resources we work with, and how they may change. No less important is a clear understanding of what we are using and how this use may change.

If methodology is inadequate to measure resource supplies, so is it in estimating demand.

Sound planning dictates comparable understanding of resource supplies and demands.

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Ecological Inventory Needs for Mine-Land Reclamation Planning[1]

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and W. O. Wilen [3]

Abstract. -- The relationship between ecological inventories and inventories requisite for the planning of programs for mined land reclamation are discussed in the context of environmental legislation, the mineral and energy needs of our culture, and the biological processes that are disrupted by mining procedures. The major components of reclamation inventories are outlined.

INTRODUCTION

Most levels of government in the United States advocate the idea of having some environmental safeguards in making use of their natural resources. This idea has become more of a reality since the passing of the National Environmental Policy Act (N.E.P.A.) of 1969. This Federal law and subsequent legislative actions have encouraged not only governmental agencies, but industrial and commercial enterprises as well to become more aware of the fact that the utilization of resources for the continuing development of our cultural and economic structure is possible without major environmental impacts. However, these legislative actions have resulted in only slight changes in customary practices utilized in the industrial development of natural resources for our day to day needs. Without a dependable knowledge of the requirements for successful planning, natural resource policies are not likely to be useful directives for any land use venture.

The environmental impact statement (E.I.S.) is the most widely recognized feature of N.E.P.A. and has now evolved into a new concept of planning analysis. An E.I.S. consists of two parts: an analysis of an operation's impacts on the environment; and a scenario of procedures required to minimize these impacts. Ideally, an environmental impact statement should include a wide range of analytical approaches including not only the technical but the cultural, sociopolitical, economic, and ecological aspects of the problem.

The initial step required in the preparation of any of the E.I.S.' component studies is the establishment of a base line inventory. The base line inventory provides the planner with the necessary information to make predictions or forecasts regarding the future condition of the environment as it may be influenced by any number of land use alterations. It is critically important then to design a comprehensive and meaningful inventory that will facilitate the accurate identification of those natural resource functions that will be impacted by the proposed land use, the sound evaluation of the impacts themselves and proper planning for their mitigation.

A wide variety of base line inventories have been developed. However, most of these do not indicate which criteria properly constitute an ecological inventory for any given land use proposal.

REVIEW OF METHODOLOGY FOR ECOLOGICAL INVENTORIES

Information obtained through litera-

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ture review provides the perspective for defining and selecting criteria most appropriate to the current needs of the ecological inventories. There is a general consensus that ecological base line inventories should include a description of the environment and a prediction of potential impacts; distinctions should also be made between man-induced effects and natural effects and between the temporal effects of short-term vs long term responses. Keenlyne (1977) outlines the basic steps for determining the impact of energy development on wildlife. The need for ecological information in the management decision process is emphasized by Johnson (1976). He also indicates that one of the goals of environmental assessment is to match the classes of perturbations with the classes of response, resulting in the prediction of ecological effects based on the measurement of key variables, potential mitigation of technological impact, and enhancement of the ecosystem. Dietz (1976) emphasizes the need to separate man-induced effects from natural effects to determine cause and effect mechanisms through the selection of parameters appropriate for the sampling of elements of ecosystem structure and function.

Studies at the individual or organism level provide insight into mechanisms of change. Investigation at the population level is necessary to estimate the number of organisms that may be removed or exploited without significantly impacting the population. Studies are conducted at the community or ecosystem level to detect variations from natural dynamics and succession. Often an impact at the ecosystem level will cause a change in the pace of naturally occurring processes; the problem, then, is the detection of additional changes above naturally occurring processes -- not the comparison of changes in various parameters over time (Sharma, 1976).

Zar (1975) states that the functional relationships between ecosystem components need to be considered in study design in order to be able to predict the effects of altering any of the components. Christensen et al (1976) emphasize that both the definition and assessment of impact should be at the ecosystem level and should involve all the structural and functional parameters important in characterizing the ecosystem.

Sharma (1976) adds that site-specific, as well as region-wide, studies are important in determining the significance of environmental impact, the former studies providing a reasonably accurate quantitative measure of the impact and the latter, information on the extent of the resource impacted.

The concepts of trophic pyramids, niches, and guilds (a guild is a functional category used for combining species that overlap significantly in their utilization of a particular resource) are proposed by French (1977) for use in explaining the organization or structure of natural systems. The structural and functional aspects of the ecosystem are divided by Barrett, et al (1976) into rate processes, state variables, and driving variables. It is agreed by Dietz (1976) and Eberhardt (1976) that a clear definition of the objectives is required in order to design a sampling program which is amenable to analysis by statistical techniques. A report from Battelle-Northwest (1974) agrees with the need for analytical rigor and in addition stresses flexibility in adapting the study to the particular site as well as providing quantitative evaluation or uniqueness rating of resources where feasible and appropriate. Buffington, et al (1976) suggest that another dimension of the assimilative capacity of a system be recognized and accounted for in impact assessment.

There exist a few common broad criteria which are generally agreed on for parameter selection. The ease of measurement, cost in time and money, and general logistical convenience fall in this category (Hirsh 1976, Johnson 1976, Battelle-Northwest 1974). It is also generally agreed that the sensitivity of the parameter to the perturbation anticipated is important. Odum and Cooley (1976) suggest the "performance curve" as a graphic form for assessment of the gradient of impact which an activity has on the system. Use of such a curve can provide predictive capability.

There exists some disagreement on the value of indicator species for purposes of impact assessment. Some, such as Battelle-Northwest (1974), feel that biological indicators should not be used because they require a high degree of interpretation by an ecologist familiar with the area, because indicators may not be comparable from site to site, and because multi-factor impacts are confounded in these indicators and become difficult to interpret in a cause and effect framework. Risser (1975), however, feels that indicator species may be valuable because they are easily understood by the non-scientific public and therefore provide a good vehicle for communicatrion. In addition, they provide an index which synthesizes the effects of undefined arrays of environmental conditions; they may also indicate inter-species interactions which could be potentially significant in the structure and function of the com-

munity. Risser does, however, suggest that they should be used only when certain conditions can be met. Buffington (1975) and Wielgolaski (1975) generally agree that indicator species may be useful but only under certain conditions; they point out the need for a considerable amount of basic research in order to confirm the effectiveness of the use of indicator species.

The literature suggests long lists of a wide variety of parameters which may be useful in ecological baseline studies. Alden (1974), Hirsh (1976), and Barrett et al (1976) suggest examples of possible parameters ranging from aesthetic characteristics of the site to measurements of the structure and function of the ecosystem. The importance of integration in ecological baseline investigations is emphasized by Cooper (1975), who suggests the measurement of such properties as ecosystem respiration, the ability to detoxify an undesirable substance, nutrient and water cycling and primary production. Absolute density or biomass density measurements of components, productivity measurements, and a variety of ratios are suggested by Battelle-Northwest (1974) and French (1977).

Following is a discussion of practical criteria for the selection of parameters to be measured in terrestrial ecological base line studies of western areas. The application of these criteria to sort from among all possible measurements a subset specific to the needs of a particular energy development activity requires knowledge of site-specific environmental characteristics. This precludes the identification of a standardized list of parameters that can be used in any base line study but rather necessitates that the user combine informed judgement with adequate system information to design the most appropriate base line study. The following is to be viewed as the approach a field biologist might take to study program design, taking into account (in a practical way) the kinds of selection criteria for parameter selection may be summarized as follows:

1) The parameter being considered should represent a significant ecological component or process or have importance as a natural resource or as a threatened or endangered species.
2) The parameter should be one upon which the proposed energy development activities are anticipated to have an effect.
3) The parameter should be identifiable, observable, and available during baseline and monitoring studies.
4) The parameter should be quantifiable by methods presently available and should be consistent with experimental design guidelines and statistical analysis requirements.
5) The parameter (and methods employed to measure it) should be cost effective (i.e., the level of effort and cost necessary to sample the parameter should be commensurate with the decision matrix and projected impacts).

The purpose of this review is to define a practical procedure for selecting the parameters most likely to meet the objectives of ecological baseline studies. However, on the whole, ecological processes are not amenable to sampling by available state-of-the-art methods. For example, it is difficult to adequately measure plant mortality or reproduction within the cost and time constraints of an ecological base line study although, particular perturbations may have direct and significant effects on these processes. The goal then is to identify ecological parameters that integrate or provide an adequate measure of the processes which can be readily measured by existing state-of-the-art methods at a supportable level of effort.

Perturbations associated with energy development activities will ultimately result in a change in one or more of the following attributes of biotic systems:

1) species composition;
2) species importance;
3) standing crop biomass; and/or
4) species distribution.

Identification of these attributes provides a conceptual framework both for integrating the major ecosystem functions anticipated to be affected by energy development activities and for identifying appropriate parameters to measure. The attributes are not, however, mutually exclusive.

Determination of species composition provides important qualitative input in the design of ecological baseline studies by ascertaining the presence of threatened or endangered species, economically important species, species with known sensitivity to certain aspects of energy development (e.g., sulfur dioxide emission) or species important to ecosystem structure and function. Changes in species composition may result from energy development-related perturbations through death of species sensitive to particular effluents, destruction of unique habitats, emigration of mobile animals intolerant of increased human activity, changes in natural successional dynamics, introduction of exotic species (e.g., for revegetation purposes), etc.

Species importance provides a means of

indicating species (and/or species functions) that achieve a measure of importance not logically falling into one of the other three categories (e.g., importance to ecosystem structure and function because of a large standing crop biomass). A species may be important because of its rare, threatened or endangered status, its economic status, its food preference, or because it performs an important ecosystem function (e.g., pollenation). For vegetation, a synthetic index exists which incorporates relative density, dominance, and frequency of the various plant species, resulting in a relative measure of species importance. Important species provide a natural focus for baseline study efforts; changes in particular attributes of these species may provide information useful in the determination of specific effects of energy development activities.

Standing crop biomass provides a measure of the importance of various ecosystem components to overall structure and function of the ecosystem. Changes in standing crop biomass caused by energy development activities will result from either a loss of individuals (i.e., reduced density) or reduction in weight of individuals (perhaps due to chronic insults such as gaseous emission or trace element accumulation).

Species distribution as defined here includes both the frequency or presence of species within defined habitats and (for mobile animals) migration patterns. Changes in species distribution from energy development activities can result from destruction of unique habitats, loss of species in habitats exposed to particular insults or impacts, or (for mobile animals) the obstruction of, or interference with, movement patterns.

Changes in each of these major attributes may be manifested at different levels of ecosystem organization. For example, reduced growth of individulals of a particular species of plant in close proximity to an energy facility may ultimately result in a decreased standing crop biomass in an entire plant community. Likewise, increased mortality of a species sensitive to sulfur dioxide emission could result in the elimination of that species and a subsequent change in community successional dynamics.

For each of the four classes of attributes defined above, parameters must be chosen that (1) provide efficient and cost-effective measures of the attributes at different levels of ecosystem organization, and (2) can be measured with existing state-of-the-art methodology.

A primary objective of the proposed approach is the measurement of responses that are expected to result from a particular perturbation. However, cause and effect relationships cannot be inferred entirely on the basis of response detection. This has been a major fault of previous base line studies. When evaluating the effects of a suspected perturbation on a major system attribute, it is important to consider that the observed change may have come about through a chain of events unrelated to the energy development of concern. This necessitates a holistic approach to base line studies. For example, vegetation characteristics are often important limiting factors with regard to animals, as plants provide their ultimate source of food and critical habitat features such as nesting sites, and frequently, their only source of water.

One of the most important aspects of designing a terrestrial ecological baseline study is the selection of methods that provide cost-effective information on selected parameters within the constraints of experimental design and statistical considerations. To date many project efforts have been devoted to the development of conceptual approaches to the design and implementation of ecological baseline studies and to the identification of parameters to be measured that are commensurate with the conceptual framework.

MINE-LAND RECLAMATION -- A DEFINITION

Mine-land reclamation in its earliest stages focused on the specific byproducts of the mining operation. This fragmentary approach is now giving way to a more comprehensive view of the problem. Reclamation as it exists today is a technology, a science and, most importantly, an ethic.

Reclamation technology originates with and embraces the mining process in its totality. It cannot be effective if it is limited to anything less than that total process. Reclamation technology integrates the mining industry's objective of developing mineral and energy resources with the motives of environmental management and protection.

Mining can be categorized into five phases: exploration, design and development, construction, operation, and closure. Each has a particular influence upon the landscape's structural and functional character.

The impacts of surface mining permeate many ecosystem components. The role ecology plays in reclamation is to integrate scien-

tific and technical disciplines in a manner that allows the accurate perception of the impact of mining upon the interacting system of biological components and their environmental structure. The primary goal of reclamation science is to simplify the quantification of important functional interactions; this can ultimately advance our understanding and management of ecosystems.

Mining as a land use activity is particularly vulnerable to criticism on the basis of the methods and manners in which its procedures are carried out; however, it is a fact that society is dependent upon the mining industry for its mineral ad energy needs. The larger problem rests within the methods ultimately chosen to maintain our present cultural system. Presently, we operate under a vaguely defined and only partially workable environmental ethic where mine lands are concerned. Technology alone cannot solve this problem; it can only alleviate the problem temporarily. Mine land reclamation is one of the most important alternatives offered in response to the need to protect and maintain the integrity of the surface landscape. The information developed by mine land reclamation projects will contribute to the eventual resolution of the larger moral and ethical questions of environmental management and cultural survival.

MINE-LAND RECLAMATION INVENTORY NEEDS

In the previous sections we have reviewed the problems inherent in establishing an ecological baseline inventory and briefly defined the component parts of mine land reclamation as it exists today. The following section will briefly outline the essential parts of a mine land reclamation inventory package.

Premined landscapes or ecosystems behave like cybernetic systems in response to stress. They have three fundamental capacities: (1) the SELF CREATIVE function is related to genetic evolution and the capacity to develop new living forms and diverse functions in response to long term stress factors; (2) the SELF REPAIR function is generally expressed as the successional development of communities leading to more stable natural communities; (3) the SELF ADJUSTNG function is related to the adaptive amplitude of each species to endure short run stresses.

Mining impacts set back ecosystems much like natural catastrophic events. Our best reclamation efforts can at best set the above capacities into motion in a definite direction. We are in fact soliciting these natural processes to work for us. What then are the critical information needs required in order to activate these repair mechanisms?

1. A Terrestrial Vegetation Inventory Component

Natural vegetation, according to Daubenmire (1976), reflects the algebraic sum of all environmental factors important to plants, better than we can judge from a consideration of all aspects of climate, topography and soils. The use of vegetative indicators does not necessarily provide any information on the physical factors responsible for growth differences. However, an analysis of the most competitive plant species can lead to the establishment of the range of growing conditions presented on any site over time.

An inventory should be conducted to identify those plant species that have been successful under premining conditions. Whatever the approach, the inventory must be considered hypothetical until validated. "A community type can be accepted as indicating an ecologically distinctive type of environment only if it shows internal consistency with respect to such features as topographic relations, soil type, hydrologic cycles and seral stages, susceptibility or resistance to disease, rates of growth, etc." (Daubenmire 1976:121)

2. A Hydrologic Inventory Component

The availability of moisture to the vegetation and the growing media constitutes a second inventory need. Water, in fact, is the key to reclamation in the west.

Surface mining activities dramatically interrupt the hydrologic function of any area. Therefore, the area's hydrological system must be clearly understood in terms of its surface water, subsurface water, precipitation, and evaporation characteristics. This information will contribute to effective planning for collection, diversion and storage capabilities of the area. In areas where productive activities depend on marginally available supplies of water, this inventory is doubly important.

3. A Soil Inventory Component

Surface mining for any mineral or energy related material will scar the land. The greater the overburden that is to be

removed, the greater will be the disturbance to that area as well as the area immediately adjacent to it. These spoil piles and overburden residuals will require stabilization treatments. The substrate may need some form of cover as well if it cannot support biological growth. It is therefore critical to sample and analyze the physical, chemical, and biological characteristics of the organic horizon and those materials that will become part of the root and infiltration layers of the reclaimed site.

4. A Climate and Air Quality Inventory Component.

Climate is a fundamental variable critical to all biological systems. Much of the information required is routinely recorded and published. Haines (1977) lists some of the sources from which this information can be obtained.

Finally, the physical and chemical constituents and variability of the air column passing over the site may be determined to be important to an inventory package. If so, the data must be established early in the inventory procedure.

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Information Requirements for Watershed Management[1]

Edwin R. Lawson[2]

Abstract.--A brief summary of the available information and information needs for watershed management is presented under two categories; broad-based and site-specific inventories. One of the areas where information is most deficient is in relation to nonpoint source pollution.

INTRODUCTION

The objective of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500)is to restore and maintain the chemical, physical, and biological integrity of the nation's water. The goals of this law are to eliminate the discharge of pollutants into the nation's water by 1985 and where feasible, provide water that is clean enough to support swimming and other recreational uses and clean enough for the protection and propagation of fish, shellfish, and wildlife by 1983. Section 208 requires that states, under the auspices of the U. S. Environmental Protection Agency, control water pollution from point and nonpoint sources. Currently, forest and range management activities are considered as potential sources of nonpoint pollution, which is initiated or caused by natural processes, including but not limited to precipitation, drainage, seepage, percolation, and runoff. To control nonpoint source pollution (NPSP), each state must develop a program to insure that "best management practices" (BMP's) are followed in all forestry operations (Singer and Maloney 1977).

In watershed management, the greatest current need for information falls within this broad spectrum of NPSP. The primary nonpoint source pollutants are:

Sediments	Dissolved solids
Nutrients	Dissolved gases
Pesticides	Thermal
Minor toxic elements	Organic materials
Pathogens	Viruses

Available data from forested and non-forested areas for each of these pollutants varies considerably, with data for some, such as pathogens, organic materials and viruses, almost totally lacking in most regions of the United States. In addition to NPSP, watershed managers must also consider the effects of management practices on total and peak runoff, ground water levels and quality, and long term site productivity.

INVENTORIES AND APPROACHES TO WATERSHED DATA ACQUISITION

Information needs for watershed management may be divided into two categories based primarily on intended application; (1) broad-based data to provide information for regional planning, and (2) site-specific data to fill gaps in knowledge of hydrologic and related processes and to make adjustments for local hydrologic conditions. The two categories may overlap considerably in some phases, because site-specific data may be required for interpretation and application of broad-based information.

Broad-Based Inventories

Inventories in this category provide general information, such as land use and topographic characteristics, over large geographic areas. Remote sensing systems, including LANDSAT (formally called ERTS or Earth Resources Technology Satellite), high altitude aircraft such as the U-2, NASA's Earth Resources Aircraft Project (ERAP), Skylab Earth Resources Experiment Package (EREP) and the National

[1]Paper presented at the Integrated Inventories of Renewable Natural Resources - A National Workshop, Tucson, Arizona, January 8-12, 1978.

[2]Project Leader, USDA, Forest Service, Southern Forest Experiment Station, Fayetteville, Arkansas.

Oceanic and Atmospheric Administration's NOAA-2 satellite, provide much useful photographic information for watershed managers.

LANDSAT effectively provides data for determining drainage patterns, basin area and shape, drainage density, and specific channel characteristics (Rango 1975). These data can provide accurate surface water inventories for water bodies as small as 0.01 km^2 (Rango 1975), because the high resolution, near infrared sensors readily discern the strong contrast between water and adjacent land. LANDSAT data have also been used to map floods (Deutsch and Ruggles 1974; Rango and Salomonson 1974), delineate floodprone areas (Rango and Anderson, 1974), map and monitor snowpacks, and estimate runoff from snowpacks (Rango, et al. 1975).

LANDSAT provides regional data every 9 days from an altitude of about 910 km. It is complemented by the U-2, which provides high resolution and small coverage from about 20 km. The EREP provides high altitude flights related to NASA's satellite and earth science missions. Low and medium altitude aircraft flights are available from several private concerns and governmental agencies. Generally, the lower flights provide more detailed information, but at a higher cost. Skylab missions in 1973-74 provided additional data from about 435 km. These data were of very high quality but were only taken once. The National Oceanic and Atmospheric Administration has three NOAA satellites which orbit North America twice daily at about 1500 km and provide data having less detail than lower level flights.

Engman (1974) discussed remote sensing possibilities for characterizing the variable source areas for streamflow in specific drainages. In his opinion, radar imagery was the most promising source of data for this purpose because: (1) radar has its own energy source and therefore it is not dependent on weather; (2) vegetation effects are eliminated; (3) the microwave energy penetrates the soil surface so that broad spectrum microwave data detect changes in soil water; and (4) computers can scan and weigh the image and thus actually produce maps of the contributing areas. Rango (1975) indicates that remote sensing could be used to collect data on river stages, water quality, ground water level and snow water equivalent, but these applications are not presently operational.

Multiple resource inventories often include data collections for watershed management. Lund and Kniesel (1975) conducted a combination aerial photo interpretation and field measurement inventory in Colorado. Data from the aerial photos pertinent to watershed management included: vegetative cover, aspect, slope, physiography, elevation, soil type and land use. Field measurements included ground and vegetative cover and estimates of erosion. For nearly all variables, predictions from photo interpretations were significantly correlated with field measurements. This approach to acquiring data is highly desirable because low-level aerial photos are readily available and data acquisition is much less expensive than field measurements.

Forest survey data pertinent to watershed management include: density and composition of vegetation; amount of litter and humus on the ground surface; percentage of bare ground; degree of compaction; amount of gullying; slope percent and position; aspect; soil texture; level of browsing; burning history; ground surface disturbance; stream channel characteristics; and land uses such as roads, agriculture, and recreation. All of these measurements are not included in every forest survey. Because small areas have few sample plots and the possibility of sampling error is high, these surveys are most useful in assessing hydrologic conditions and problems in a rather large geographic region.

The Soil Conservation Service collects data on hydrologic conditions and soil characteristics in their standard soil surveys and land classification surveys, such as the Arkansas Conservation Needs Inventory (U. S. Soil Conservation Service 1969). In some states, detailed soil surveys of forested areas have not been completed, which is a serious deficiency in management planning.

The U. S. Geological Survey has collected and summarized streamflow and water quality data from a nationwide network of stations. These data are useful for monitoring changes in streamflow characteristics and water quality of basins the stations represent, but water quality data have not been collected in many areas where extensive land use changes have occurred.

Considerable broad-based data for watershed management are available from many sources. The greatest deficiency at this time, however, is that much of the data has not been summarized and made readily available or it is not retrievable on a basis that fits the needs of the user. For example, information that is available only on the basis of county and state boundaries may be of little use to planners who need information on the basis of physiographic provinces.

Site-Specific Data

Considerable site-specific information on some areas of watershed management is available. Anderson, Hoover, and Reinhart (1976) recently summarized much of the available information on effects of forest management on floods, sedimentation, and water supply. The EPA requirement that each state develop BMP's

has resulted in increased efforts to summarize available information on NPSP.

The Forest Service, in cooperation with the Environmental Protection Agency, is preparing a handbook on Water Resources Evaluation Nonpoint Sources Silviculture (WRENS). The goal of this endeavor is to provide a site-specific process-oriented analysis that has nationwide application and can lead the user to silvicultural management prescriptions that incorporate the nonpoint pollution process and its potential effect on water resources. This analysis should enable the user to prescribe appropriate controls that will minimize NPSP from silvicultural activities.

Data from forest surveys are also site-specific and provide information that may be useful in developing relationships among site-factors, or perhaps determining the reliability of erosion estimators such as the Universal Soil Loss Equation. These surveys are repeated and therefore offer opportunity for remeasurement.

To determine where information deficiencies occur, the U. S. Forest Service prepared, in cooperation with EPA, a comprehensive analysis of research and development needs on forest and rangelands (U. S. Forest Service 1977). The objective of this proposed research and development program is to develop, where needed, improved methods for predicting, evaluating, and controlling NPSP on forest lands and rangelands. Selection of the research and development components was based largely on the rationale that knowledge of physical and biological processes is essential to predictions of NPSP responses to forest management activities. Important targets developed in the analysis are:

(1) Improved methods for assessing, predicting, and controlling NPSP.
(2) Improved assessment of NPSP effects on ecosystems.
(3) Improved methods and criteria for evaluating socioeconomic effects of NPSP and NPSP controls.
(4) Improved tools for NPSP management.

In most areas of the country, sufficient site-specific data are not available to adequately assess the impacts of various forest practices on water quality and other forest resources. For example, sediment and nutrient loadings in some major streams can be estimated fairly accurately, but sediment and nutrient losses from specific sites and management activities in the drainage basin are relatively unknown.

Data needed in applying some process models are often unavailable. For example, some hydrologic models developed to estimate streamflow responses require complex soil information and solar radiation data, which are generally not available.

Lack of water quality data from relatively undisturbed areas is almost a universal problem. Because of this deficiency, some NPSP regulations with unrealistic goals are being developed. Data from a wide variety of site conditions are needed to determine the variability of pollutants in these "natural" waters.

Both site-specific and broad-based data could be made more useful if standardized techniques and procedures were used. Some efforts have been made toward this objective. For example, standardized procedures for chemical analysis of water and wastes have been developed by EPA (U. S. Environmental Protection Agency 1976), and a National Handbook of Recommended Methods for Water-Data Acquisition has been provided by the U. S. Geological Survey (1977). Standardization of techniques and procedures will allow regional comparisons of data, and thus greatly facilitate development of appropriate watershed management guidelines.

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Panel II — Current Resource Inventory Techniques: Moderator's Comments

Thomas E. Avery[1]

These presentations, prepared by recognized scientists in diverse fields, will describe the "state of the art" in surveys of timber, water, wildlife, fisheries, rangelands, soils, outdoor recreation, and national heritage sites.

Although the diversity of subject matter precludes a capsule summary of ideas advanced, the total offering should be of interest and utility to all of us who are concerned with integrated resource inventories.

A a member of the SAF Committee on Metrication, I would like to solicit suggestions from the Inventory Working Group as to how and when the metric system should be implemented (in the forestry and wood products industries) in the United States. The change is eventually inevitable; the sooner we make plans for an orderly conversion, the better for all of us!

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The Opportunity Spectrum Concept and Behavioral Information in Outdoor Recreation Resource Supply Inventories: Background and Application[1]

P. J. Brown, B. L. Driver, and C. McConnell[2]

The paper describes an outdoor recreation resource (ORR) Supply Inventory and Classification (SIC) System that is being developed for multiple use natural resource planning. Four previously developed ORR SIC's on which this system was built are described briefly. A general model for natural resource planning is presented to show how the proposed ORR SIC fits into a larger planning framework.

The proposed SIC System is described and its application for regional and unit planning is explained. Relationships between OR consumers' preferences for specific types of satisfying experiences and their preferences for specific attributes of the physical, social, and managerial settings are translated into specific and objective criteria proposed for inventorying and classifying lands as to their potential for providing particular types of OR opportunities on the spectrum.

Recreation resource supply inventories are fundamental to multiple use natural resource planning and management decisions. Therefore, it is important to have a sound system for making these inventories and for classifying the resource base.

Several criteria can be applied to evaluate the soundness of an outdoor recreation resource (ORR) supply inventory and classification (SIC) system. Those guiding the development of the system reported in this paper were:

1. It should have intuitive appeal to managers and give relevant and useful results.

2. It should be adaptable to the land planning and management processes (or models) being used by different agencies.

3. It should give consistent results when replicated in the same area by different people.

4. It should provide objective criteria for evaluating the recreation opportunity potential of different types of resources or landscapes.

5. It should assure that the total range of OR opportunities are covered.

6. It should not be overly complex and expensive to implement.

7. It should be based on tested social and behavioral science theories that are relevant to OR choice. OR opportunities must be defined in human as well as physical resource terms simply because of the nature of the demand for these services.

8. It should build on existing systems, if possible.

We feel that each of these criteria is met by the ORR SIC system presented here. A companion paper in these proceedings presents the conceptual scaffold on which this behaviorally based system was built (Driver and Brown.)

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[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan. 8-12, 1978.

[2]Associate Professor, Department of Recreation Resources, Colorado State University; Recreation Research Project Leader, Rocky Mountain Forest and Range Experiment Station; and Recreation Staff Officer, Region 2, USDA, respectively.

In this paper we first describe a general planning framework into which our SIC fits. Then other ORR SIC's being used by resource management agencies are reviewed briefly. Finally, the application of the proposed SIC system is described for two levels of planning, area (or regional) plans and forest/unit plans. The system is useful for guiding site planning efforts too, but space does not permit elaboration of its application at that level.

A General Framework for ORR Planning

A general ORR planning process is common to most resource management agencies, though some emphasize different parts of the process. Figure 1 depicts an overview of this process and its integration into multiple use resource planning.

As indicated in box 1 of figure 1, ORR planning begins with a problem identification phase. This phase involves public participation activities, other external pressures for planning, and in-agency study and discussion.

After an expressed and felt need for planning is recognized, analyses of consumer preferences (2a), recreation participation (2b), and demand (3) are made. Consumer and participation analysis are divided into two boxes in the diagram to emphasize the current state of the art. Participation analyses are usually activity oriented and consist of counting the number of participants and time spent recreating during a fixed period of time. These data are usually incorporated into demand analysis through projection of past trends.

Consumer analyses represent a wider range of topics. Studies of user characteristics and preferences which usually focus on the preferred components of a quality experience are involved. The types of satisfaction that are desired are measured as well as attributes of physical, social, and managerial settings perceived by consumers as being important to their satisfaction. These attributes define the total environmental setting in which the OR activity takes place. (Driver and Brown, these proceedings) Consumer analyses of these physical, social, and managerial setting attributes feed directly into capability and suitability analyses (5 and 6).

Demand analysis produces an estimate of the quantity and quality of a specific activity or experience opportunity demanded.[3] The output is a list of activity and experience opportunities to which subsequent inventory and planning activities are to be responsive. Although demand estimation is linked directly to both capability and suitability analyses, steps should be taken to assure that highly demanded opportunities are not overlooked during the inventory (box 4). Decision rules used to prioritize demands might focus on the largest demands, protection of minority demands, or demands for recreation opportunities which are highly resource dependent.

Box 5 reflects the capability analysis phase. Capability is the inherent potential of a long or water unit to provide specified goods or services according to clearly defined criteria.[4] The criteria are quantities and qualities of specific physical attributes of the land or water base. Since the criteria are specific, capability is measured as capable or not capable. To the extent possible, the criteria should be objective and not require subjective judgements by the person making the inventory.

The physical resource inventory is a component of capability analysis. As such, the resource elements need to be inventoried in terms of their potential for providing specific activity and experience opportunities. This is accomplished by using explicit and clear criteria which are set and defined before the supply inventory is started. By using fixed criteria (which can be changed if they are found inapplicable), an area can be evaluated as capable or not capable of providing an opportunity. The output from the capability analysis is a list of demanded activity and experience opportunities that the land and water base is inherently capable of producing. This list might be expanded or shortened by management activities considered in the suitability analysis.

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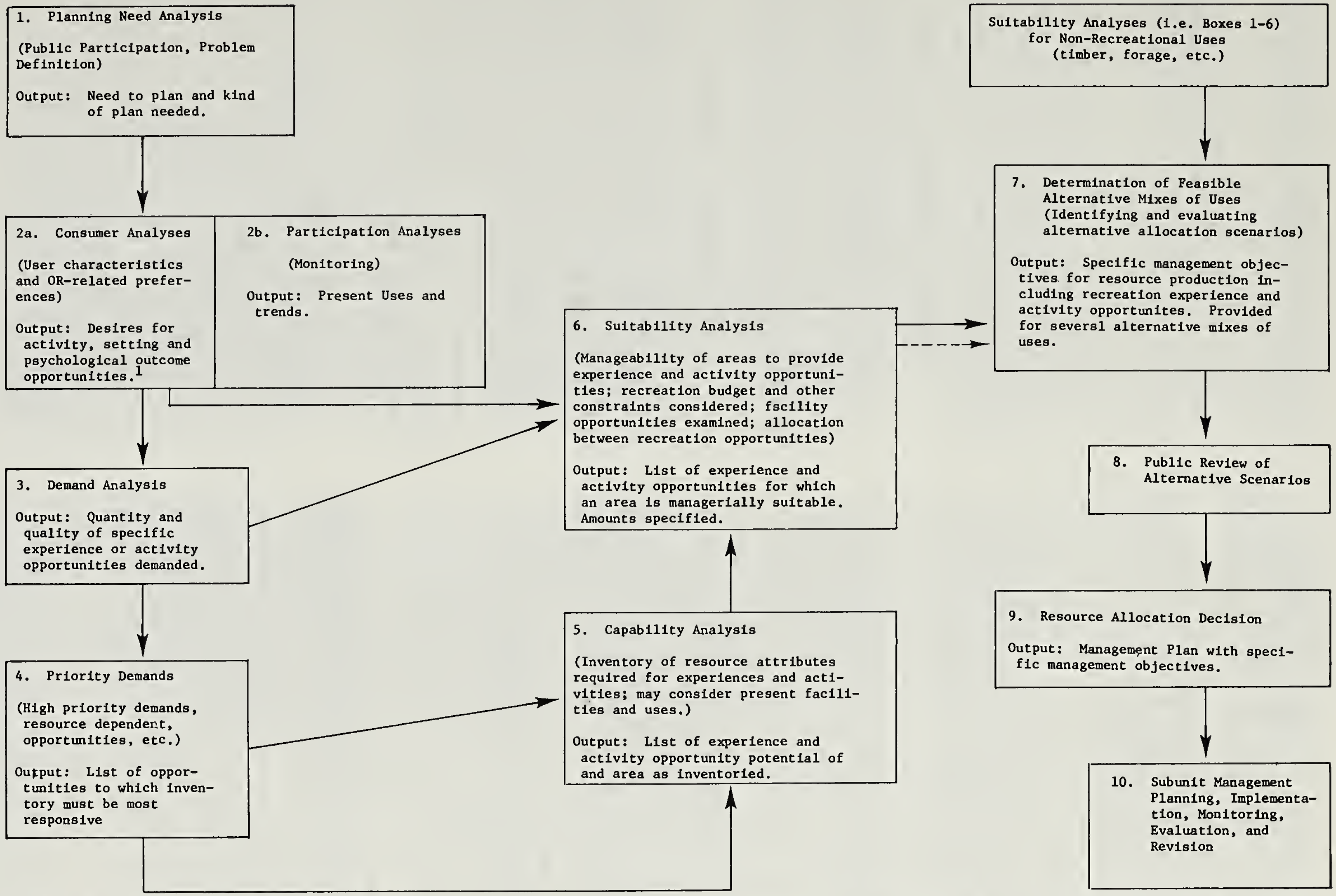
[3]An experience opportunity is defined as that bundle of desired and expected psychological outcomes which are valued the highest by a particular user or user group. See the Driver and Brown paper in these proceedings for a fuller definition.

[4]This definition of capability, and the subsequent definition given for suitability, is consistent with definitions given in the Wildland Planning glossary by Schwarz et al. 1976.



[1]See the Driver and Brown paper in these proceedings.

Figure 1. A General Framework for Outdoor Recreation Resource Planning.

Suitability analysis is represented in Box 6. Suitability refers to an estimation of the manageability of an area to provide specified activity and experience opportunities. Well defined criteria defining the quantities and qualities of the physical, social and managerial attributes necessary to manage the land effectively to provide desired recreation opportunities are necessary. Since the criteria are specific, suitability is indicated as suitable or not suitable.

In addition to classifying areas as suitable or not suitable for specific recreations opportunities, a capacity estimate is made for those areas classified as suitable. This capacity estimate enables the planner to indicate specific output associated with an allocation decision.

The suitability analysis is conducted in the same way as the capability analysis, but considers more items. Available management tools, budgets, personnel, technology, public acceptance, the presence of unique-rare features, and policy constraints are all important items. The effect of each of these items on whether or not it is managerially feasible to realize the inherent capability, or to modify it, must be weighed by the planner. The output from this process is a list of demanded activity and experience opportunities and the quantity of each opportunity that is managerially feasible to provide. This list might be carried to the next stage, identifying alternative mixes of uses (7), or it might be subjected to a compatibility analysis and recreation resource allocation. Because of competing uses for the resources, it is most likely that a decision will be made at this point to reduce the number of suitable recreation opportunities to move forward to the next stage.

Suitability analysis producing a list of the types and quantities of recreation opportunities which can be provided, represents the end of the recreation inventory and planning system (boxes 1-6 in figure 1). The output from the suitability analysis is then meshed with the outputs from similar systems for other goods and services (7) to produce alternative multiple use resource allocation plans. Here, recreation must compete with demands for other goods and services that the land base can provide. The output of box 7 is alternative allocation proposals that the public can review (8). A resource allocation decision is made from among these plans as they are modified by public review (9). This plan will contain specific management objectives relating to recreation uses. These objectives should be described in terms of specific physical, social, and managerial setting attributes which make the activity and experience opportunities possible.

The specific recreation management objectives are the basis for developing more specific recreation plans below the forest plan level, for implementation of the unit plan, and for recreation system evaluation and revision (10).

The SIC system we have developed is first used in box 5 for capability analyses. Because it is a land classification as well as an inventory system, the logic of the system can be carried throughout the entire planning framework.

Reviews of Selected SIC Systems

Several ORR SIC systems have been developed over the past few years. Each has some strong points in theory, logic, simplicity, or comprehensiveness; but, each also has some serious limitations for use in ORR inventory and assessment. The systems used as a foundation for the system we propose are briefly described.

BOR Area Classification Plan

The purpose of the Bureau of Outdoor Recreation Area Classification Plan (ACP) is to provide a common framework for classifying recreation resources. The approach of ACP is cited as recreation zoning based upon relationships between physical resource characteristics and public recreation needs. The system attempts to encompass the full range of physical resources needed for all kinds of outdoor recreation activity and specify the types of management required for optimum recreation uses of each area. While the classification is based primarily on physical features, economic and social variables are important in classifying an area with the ACP.

The ACP is designed for applicability to large geographical areas regardless of land ownership. All land with a potential for recreation is divided into the following classes: Class I, high density recreation areas; Class II, general outdoor recreation areas; Class III, natural environment areas; Class IV, outstanding natural areas; Class V, primitive areas; Class VI, historic and cultural sites. The area classification is based on a general description, the types of activities which take place, the degree of development, and agency responsibility and management recommendations. The classification system does not represent a continuum based on a combination of these variables.

Quite broadly, Classes I, II, and III are separated primarily in terms of their proximity to an urban setting and degree of development. Class IV is chiefly a measure of the uniqueness of the natural setting, and Class VI is distinguished as having historic value. Class V is the designation given to congressionally and administratively designated wilderness and primitive areas.

The method of assigning an area its class code is largely subjective. In addition to classifying an area in terms of the guidelines mentioned above, the ACP recommends that the classification process also give attention to economic and social considerations, public needs for different kinds of recreation opportunity, uses of other natural resources, and objectives of the land owner. The ACP also suggests that when the physical features and location of an area permits it to be classified in more than one class, it should be placed in the class which will produce optimum recreation values in the long run.

The most serious shortcoming of the BOR Area Classification Plan is that its criteria for classifying areas are too general and require too much subjective judgment on the part of the planner. In addition, it is unclear if the system represents an inventory classification based on the inherent recreationa potential of the area or, instead, a suitability classification based on what the agency feels the area <u>should</u> offer. There is a lack of distinction between identification of the inherent capability of an area and recommendations based on management philosophy and policy without sufficient attention given to separate and systematic capability and suitability analyses.

<u>Recreation Opportunity Inventory and Evaluation</u>

The Recreation Opportunity Inventory and Evaluation (ROIE), developed in Region 1 of the USDA Forest Service, attempts to identify potential recreation opportunities as well as potential recreation uses. Activity preferences serve as the base for inventory and evaluation. These preferences have been grouped into preference types: active-appreciative, active-extractive, passive appreciative, sociable-learning, and active-expressive. Elements of the environment relating to each of these preference types are inventoried first. Then, the land is classified according to its capability to provide opportunities for one or more types. These two processes result in a measurement of recreation opportunity by preference type for each unit of land. The land units delineated are called Recreation Experience Units (REU's).

Once lands have been classified to show the opportunities available for each preference type, social visitation capacities are estimated. Several kinds of quantitative data are combined to provide these estimates.

The ROIE has several factors which make it a good recreation inventory and planning system. First, it focuses on inventorying opportunities to meet recreationists' preferences. Second, it attempts to relate environmental attributes to the preference types. And, third, it enables capacity estimation.

One limitation of the method is its limited foundation in empirical research. Both the lists of preference types and environmental attributes were judgmentally produced, and the relationships between these two lists are inferred. Other limitations relate to the cost and complexity of the system caused by using unnecessary mathematical synthesis of the data, the frequent use of subjective ratings, and criteria which limit the method's applicability to mountainous terrain.

<u>Recreation Inventory Instructions</u>

The Recreation Inventory Instructions (RII)[5] attempt to specify and describe the attributes of forestland in terms of kind, quality, and amount of recreation use which it is capable of supporting without unacceptable depreciation. There is an implied behavioral base to this method since recreation is defined as the response of people to certain basic needs or motives.

Measurements of quality and quantity are made for three phases of the recreation resource:

1. Dispersed Phase--a description of lands and waters with characteristics for activities which occur in dispersed forms.

2. Intensive Phase--a description of lands and water with the characteristics for development to support recreation activities which occur in relatively concentrated or mass form.

3. Visual Phase--a description of selected individual features, objects, or conditions of prominence which contribute to scenery as viewed by people.

For each of these phases, qualitative criteria are evaluated and summary indexes are produced. The higher the summary index for each phase,

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[5]Developed by Gordon Sanford and included in Forest Service Manual Section Nos. 2303.1 and 2331.11c, as of November 1977.

the higher the land quality for providing those recreation activity opportunities described for that phase.

Capacity estimates are generated for the classified lands using either comparative analyses or using generalized RII guidelines. Where appropriate, the RII relies on RIM procedures for estimating capacity.[6]

The structure of RII is a solid approach to the inventory process. It assumes a behavioral orientation although the theoretical basis for this is not explicit. It attempts to relate land area attributes to recreation experience classes. It provides a procedure for estimating capacity. And, it attempts to mesh with other recreation planning and management procedures, like those in the Forest Service's RIM system.

The RII is limited by not being founded upon an empirical research base. Additionally, some of the psychological notions underlying the method appear to be erroneous. A further complication with RII is its specification of experience levels which implicitly puts a premium on primitive and natural environment types of recreation. Finally, the system is not easy to implement in its entirety.

Canadian Land Inventory

The Canadian Land Inventory (CLI) is a straightforward way to arrive at estimates of recreational capability. The method provides an overview of the quality, quantity, and distribution of natural recreation resources. The basic inventory unit is the land form or land unit which is delineated by the relative homogeneity of physical features within that unit.

Based upon a set of resource attributes related to activity subclasses, the capability of the land to provide opportunity for each activity subclass is measured. Subjective judgments are then used to produce class rankings for each land unit. These rankings range from very high capability to very low capability.

The CLI provides a basic organizing framework for recreational inventory that is simple and easy to implement. It also makes the relationship of inventory to the planning process explicit by inventorying to produce estimates of capability.

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[6]RIM designates the Recreation Information Management System of the USDA Forest Service which is used to collect and store recreation participation data.

This system has not taken advantage of the results of recreation behavioral research. However, it can easily incorporate research data or attribute-activity relationships as they become available. Another shortcoming is that it uses only activity classes and subclasses without any recognition of the specific experience opportunities demanded, or to be supplied. The method also does not incorporate suitability analyses or lead to estimation of capacity--both of which are necessary for ORR planning.

Summary of Review of Other SIC Systems

The ACP system has limited applicability to ORR supply inventory needs of most resource management agencies. Several good ideas, however, are embodied in the ROIE, RII, and CLI systems, and can be used in development of a better SIC system. A better system could derive its framework from the CLI and specify a relationship between experience opportunities and attributes of the physical, social, and managerial settings in which preferred experiences take place. Like the CLI, the improved system should involve an identification of inherent capability based upon inventory and evaluation of the physical attributes of the land and water base. It should go beyond the CLI and deal with suitability analysis as well. Like the ROIE, the system should be behaviorally based and acknowledge the importance of user preferences. And, like the ROIE and the RII, the system should deal with experience opportunities and with generating quantitative estimates of opportunity (capacities). Our proposed SIC system has built on the strong points of each approach.

Proposed ORR SIC System

Outdoor recreation resource planning takes place at several levels: (1) national planning; (2) area or regional planning; (3) subarea planning (e.g., forest); (4) unit planning; and (5) site planning within management units. The SIC discussed in this paper has been developed for regional, forest, and unit level planning. is applicable to other levels as well, but that has not been our focus.

Regional ORR Supply Inventories

The regional ORR SIC system we propose is being developed in Region 2 of the USDA Forest Service. In structure, it builds upon the foundations provided by the ROIE, RII, and CLI systems previously discussed. It is a system which recognizes the need to specify both experience opportunities and settings (physical, social, and managerial) in which the opportunities can be provided. It also recognizes the state of the art which presently can be applied

to regional recreation planning efforts and, in most cases, can be applied to unit and sub-regional planning as well.

As explained in detail in the Driver and Brown paper in these proceedings, the SIC we are developing is based on the concept of a recreation opportunity spectrum (Wager 1966; Lloyd and Fisher 1972; Stankey 1977; Driver and Brown, these proceedings) with the spectrum defined in terms of experience opportunities. We have labeled it the Recreation Opportunity Resource and Classification System, or RORCS for short. The experience opportunity classes defined by the spectrum and their associated physical, social, and managerial settings are shown in table 1. That table was modified from Gordon Sanford's Experience Levels, which are a part of the RII approach reviewed previously. (See Forest Service Manual Section Nos. 2303.1 and 2331.11c, as of November 1977.) For simplicity, the experience opportunity classes are labeled primitive, semi-primitive non-motorized, semi-primitive motorized, rustic, concentrated, and modern urbanized. Specific activity opportunities can be associated with each point on the spectrum.

To identify lands capable of producing different opportunities at the different points on the spectrum, a set of specific criteria is necessary. Table 2 contains sample criteria, a lengthy list was narrowed to the four shown in order to keep the system simple. Also, we believe that too many criteria are: (1) size of area; (2) remoteness; (3) irreversible evidence of man; and (4) renewable resource modification. Specific standards for each criterion and each recreation opportunity class are also given in Table 2. Those standards are objective but they allow the planner to use his professional judgment. Also, they are being modified as the system is being applied.

Using Table 2 to identify capability follows a sequential process. First, remoteness is assessed by drawing lines on a map at the intervals from roads, with the intervals shown in the table. Once these lines are drawn, the area inside connecting lines can be calculated. Then, based upon inventories of permanent evidences of man and renewable resource alteration, one can describe the amount of area affected.

To apply the standards to determine recreaction opportunity classes on the spectrum, the planner need only match the mapped or calculated data to the values given in each row of the table. For instance, if an area of 10,000 acres was located more than three miles from any constructed road, contained less than one percent of its area in an irreversibly modified state, and had been grazed by cattle over 20 percent of its area, (a nonpermanent alteration) it would be capable of producing all six types of opportunity. If cattle grazing had taken place over 45 percent of the area, then the applicable recreation opportunity classes would exclude primitive. An indication that multiple opportunities can be provided recognizes that developments and changes in the resource base preclude less development-oriented recreation, but that more development-oriented opportunities are not restricted by the resource base. Development-oriented opportunities depend primarily upon investment levels.

After the recreation opportunity capability class on the spectrum has been identified, coefficients can be applied to indicate the capacity, or possible production output, for each classified area. Sample maximum supply coefficients are shown in Table 3. These could be adjusted for season of use, total area, or to persons at one time with very little effort.

Application of the RORCS at the regional level actually combines capability and suitability analyses into one step. This seems reasonable to us at the regional level because the recreation opportunities examined are general, and regional plans usually have a policy-guidance focus, rather than a specific on-the-ground action focus. If a recreation planner needed to know which specific recreation opportunities to supply, more specific physical resource, social, and management setting information would be required and the planning process could be divided into more discrete steps like capability and suitability analyses.

While use of this system was successfully demonstrated on the Pike National Forest, it is still being developed. Two major limitations of the system are the limited research base for setting criterion standards and for deriving capacity coefficients.

Unit ORR Supply Inventory

Within each of the outdoor recreation opportunity classes identified by using the RORCS at the regional level, there are many activity and specific experience opportunities. For each appropriate activity within one of the regional recreation opportunities, there is a specific experience opportunity made up of the bundle of most preferred psychological outcomes. For each specific experience opportunity there are many physical, social, and managerial attributes of the recreation setting which help users have high quality experiences.

Table 1. The Recreation Opportunity and Resource Classification Spectrum, with the associated experience opportunity classes and their associated physical, social, and managerial settings requirements.

Opportunity Class	Experience Opportunity	Physical, Social, and Managerial Setting
Primitive (P)	Opportunity for isolation (from the sights and sounds of man), to feel a part of the natural environment, to have a high degree of challenge and risk, and to use outdoor skills.	Area is characterized by essentially unmodified natural environment of fairly large size. Concentration of users is very low and evidence of other area users is minimal. The area is managed to be essentially free from evidence of man-induced restrictions and controls. Only essential facilities for resource protection are used and are constructed of on-site materials. No facilities for comfort or convenience of the user are provided. Spacing of groups is informal and dispersed to minimize contacts with other groups or individuals. Motorized use within the area is not permitted.
Semi-primitive non-motorized (SPNM)	Some opportunity for isolation from the sight and sounds of man, but not as important as for primitive opportunities. Opportunity to have a high degree of interaction with the natural environment, to have moderate challenge and risk, and to use outdoor skills.	Area is characterized by a predominantly unmodified natural environment of moderate to large size. Concentration of users is low, but there is often evidence of other area users. The area is managed in such a way that minimum on-site controls and restrictions may be present, but are subtle. Facilities are primarily provided for the protection of resource values and safety of users. On-site materials are used where possible. Spacing of groups may be formalized to disperse use and provide low-to-moderate contacts with other groups or individuals. Motorized use is not permitted.
Semi-primitive motorized (SPM)	Some opportunity for isolation from the sights and sounds of man, but not as important as for primitive opportunities. Opportunity to have a high degree of interaction with the natural environment, to have moderate challenge and risk, and to use outdoor skills. Explicit opportunity to use motorized equipment while in the area.	Area is characterized by a predominantly unmodified natural environment of moderate to large size. Concentration of users is low, but there is often evidence of other area users. The area is managed in such a way that minimum on-site controls and restrictions may be present, but are subtle. Facilities are primarily provided for the protection of resource values and safety of users. On-site materials are used where possible. Spacing of groups may be formalized to disperse use and provide low-to-moderate contacts with other groups or individuals. Motorized use is permitted.

Table 1. (Continued)

Opportunity Class	Experience Opportunity	Physical, Social, and Managerial Setting
Rustic (R)	About equal opportunities for affiliation with user groups and opportunities for isolation from sights and sounds of man. Opportunity to have a high degree of interaction with the natural environment. Challenge and risk opportunities are not very important. Practice and testing of outdoor skills may be important. Opportunities for both motorized and non-motorized forms of recreation are possible.	Area is characterized by predominantly natural environment with moderate evidences of the sights and sounds of man. Such evidences usually harmonize with the natural environment. Concentration of users may be low to moderate with facilities sometimes provided for group activity. Evidence of other users is prevalent. Controls and regimentation offer a sense of security and are on-site. Rustic facilities are provided for convenience of the user as well as for safety and resource protection. Moderate densities of groups is provided for in developed sites and on roads and trails. Low to moderate densities prevail away from developed sites and facilities. Renewable resource modification and utilization practices are evident, but harmonize with the natural environment. Conventional motorized use is provided for in construction standards and design of facilities.
Concentrated (C)	Opportunities to experience affiliation with individuals and groups are prevalent as is the convenience of sites and opportunities. These factors are generally more important than the setting of the physical environment. Opportunities for wildland challenges, risk taking, and testing of outdoor skills are unimportant, except for those activities like downhill skiing for which challenge and risk taking are important.	Area is characterized by substantially modified natural environment. Renewable resource modification and utilization practices are primarily to enhance specific recreation activities and to maintain vegetative cover and soil. Sights and sounds of man are readily evident, and the concentration of users is often moderate to high. A considerable number of facilities are designed for use by a large number of people. Facilities are often provided for special activities. Moderate to high densities of groups and individuals are provided for in developed sites, on roads and trails, and water surfaces. Moderate densities are provided for away from developed sites. Facilities for intensified motorized use and parking are available.

Table 1. (Continued)

Opportunity Class	Experience Opportunity	Physical, Social, and Managerial Setting
Modern urbanized (MU)	Opportunities to experience affiliation with individuals and groups are prevalent as is the convenience of sites and opportunities. These factors are more important than the setting of the physical environment. Opportunities for wildland challenges, risk taking, and testing outdoor skills are unimportant.	Area is characterized by a substantially urbanized environment, although the background may have natural elements. Renewable resource modification and utilization practices are to enhance specific recreation activities. Vegetative cover is often exotic and manicured. Soil protection usually accomplished with hand surfacing and terracing. Sights and sounds of man, on-site, are predominant. Large numbers of users can be expected both on-site and in nearby areas. A considerable number of facilities are designed for the use and convenience of large numbers of people and include electrical hookups and contemporary sanitation services. Controls and regimentation are obvious and numerous. Facilities are provided for special activities. Facilities are highly intensified motor use and parking are available with forms of mass transit often available to carry people throughout the site.

At the forest and unit levels, additional information is needed which enables identification of capability and suitability to produce opportunities for specific psychological outcomes. It is necessary to estimate capacity along with identification.

The state of the art generally does not allow the degree of specification needed. Most preferred psychological outcomes for most activities are not yet fully defined, though research is beginning to provide needed answers (Driver 1976a & b; Driver and Knopf 1977; Brown et al. 1977; Hautalouma and Brown 1977; Driver and Cooksey 1978). Also, far too little is known about the situational attributes which facilitate satisfying recreational experiences.

To meet these informational needs we have begun research to identify relationships between specific experience opportunities and physical resource attributes. Initial studies looked at the two components separately while our current work attempts to integrate them. Most of that current work focuses on primitive and semi-primitive non-motorized opportunities and environments.

We have identified several of the psychological outcomes desired by users of the Rawah Wilderness and have identified groups of users desiring similar sets of outcomes.[7] In the Rawah, five user groups were identified. These groups have different preferences with the two most different desiring: (1) only opportunities to experience nature and a change from home and work environments, and (2) opportunities to experience nature, a change from home and work environments, challenge, freedom of time and movement, self-realization, and risk-taking.

In the Indian Peaks backcountry, located south of Rocky Mountain National Park in Colorado's Front Range, we began our examination of physical resource attributes identified by recreationists as contributing to or detracting from their recreational satisfaction.[8] In that study, nine dimensions of the resource base were identified which either added to or detracted from the user's recreation experience.

[7]This study was supported by the McIntire-Stennis Forestry Research Program at Colorado State University, project No. 5358.

[8]This study was supported by the RPA Research and Development project of the Rocky Mountain Forest and Range Experiment Station, cooperative agreement 16-681-CA.

Table 2. Recreation opportunity capability criteria.

Criterion name	Required standard by opportunity class					
	P	SPNM	SPM	R	C	MU
Size of area (acres)	≥ 5000	≥ 2500	≥ 5000	≥ 1	≥ 1	≥ 1
Remoteness (sights and sounds of man) (miles or equivalent screening)	≥ 3 miles from any constructed road	> 1/4 mile from any constructed road	≥ 1/4 mile from any constructed road	≥ 1/4 mile from any primary road	≥ 1/4 mile from any primary road	≥ 0 miles from any road
Irreversible evidence of man (mines, reservoirs, roads, etc. which cannot be feasibly obliterated) (% of total area)	0-1% of area	0-5% of area	0-5% of area	0-25% of area	0-100% of area	0-100% of area
Renewable resource modification (Nonpermanent alteration natural environment) (% of total area)	0-30% of area	0-70% of area	0-70% of area	0-70% of area	0-100% of area	0-100% of area

These nine attribute dimensions are listed in Table 4 along with a description which indicates how much each addes to or detracts from the perceived level of satisfaction. Most of the attribute dimensions have positive values and are perceived as adding to satisfaction with the meadow-forest and water related dimensions being the most positive. Intrusions are perceived as detracting from positive recreational experiences.

The next step in this research is to integrate the two kinds of information. Our first study designed for this purpose is of users of the Flat Tops Wilderness in western Colorado.[9] The same psychological outcome measurement scales used in the Rawah and the same resource attribute scales used in the Indian Peaks were employed in the Flat Tops study. Analysis is currently underway, and it appears that it is possible to relate specific resource attributes to specific sets of psychological outcomes (or experiences) preferred by Flat Tops users.

The ability to relate resource attributes to sets of psychological outcomes fits precisely the needs of our proposed application of the RORCS at the forest and planning unit level. To accomplish an experience opportunity capability analysis, it is necessary to know which resource attributes are necessary for each experience opportunity and which detract from each opportunity.

While the relationships between experience opportunities and physical resource attributes are being determined, three other components of the ORR SIC process need to be studied.

[9]This study has been supported by the McIntire-Stennis Forestry Research program at Colorado State University, project 5348 and the Rocky Mountain Forest and Range Experiment Station, cooperative agreement 16-646-CA.

Table 3. Hypothetical recreation day coefficients to determine maximum supply.

Opportunity Class	Coefficients
Primitive (P)	8 Recreation days/acre/year
Semi-primitive non-motorized (SPNM)	20 Recreation days/acre/year
Semi-primitive motorized (SPM)	20 Recreation days/acre/year
Rustic (R)	1,800 Recreation days/acre/year
Concentrated (C)	7,300 Recreation days/acre/year
Modern urbanized (MU)	36,500 Recreation days/acre/year

Table 4. Effect of the nine resource attribute dimensions identified in the Indian Peaks study on perceived level of satisfaction.

Dimen Dimension	Effect on user's perceived level of satisfaction
Meadow-forest	Adds strongly
Water related	Adds strongly
Wildlife	Adds moderately to strongly
Dense vegetation	Adds moderately
Rugged topography	Adds moderately
Rare or unique natural features	Adds moderately
Fish related	Adds moderately
Nuisances	Neither adds no detracts
Intrusions	Slightly detracts

First, there is a need to develop measurement techniques for the physical resource attributes. Second, there is a need to identify and measure preferred social and management attributes of the recreational setting. Third, there is a need to determine maximum (and in some cases, minimum) capacity levels for different experience opportunities.

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Techniques and Principles of Stream Fisheries Surveys[1]

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Abstract.--The need exists for stream fisheries surveys to move away from mere component analysis, wherein factors and organisms are treated as if they were independent entities, to more holistic approaches wherein interactive, integrative, and emergent properties are also included. Tools and techniques available for this task are relatively adequate if a more innovative systems-level approach were adopted.

INTRODUCTION

Catering to the vocational compulsion of resource managers to maximize something, it may be assumed that the resource inventory is the beginning step in such process. Fundamental to maximization of social benefit by actions of land planners and managers is the adequacy of available techniques and principles in providing the requisite insight for rational decision making.

In sport fishery management we possess a technical capability which drastically outpaces our social wisdom. As in so many other endeavors, the track record is one of trying to manage our resources to match social trends and, often inadvertently, generating new trends in the attempt (McFadden 1969). Accordingly, there has been increasing emphasis in understanding man's and nature's world as a functional whole. The same should apply to technological assessment of streams, away from mere component analysis, wherein factors and organisms are treated as if they were independent entities, to more holistic approaches which include interactive, integrative, and emergent properties (McFadden 1969, Odum 1977).

PRINCIPLES

Attempting to understand stream phenomena by detailed study of smaller and smaller componets and then synthesizing the parts into a functional whole involves large-scale complexity at each hierarchical level. Physical-chemical requirements of stream fish species have been the subject of much research but researchers acknowledge that there are many relationships not yet understood. Recent literature reviews by Bovee (1974), Giger (1973), Hooper (1973), Hunter (1973), and Platts (1974) show that many qualitative relationships between biological and physical requirements of fish are recognized, but interactions between factors that make up the stream environment are so numerous that expression of these relationships in quantitative terms is next to impossible. Overwhelming complexity can be countered with overriding simplicity (Odum 1977). Lack of understanding of complex interrelationships in fisheries has been effectively addressed by identifying and correcting limiting factors.

As a first working principle in stream surveys, the question needs to be asked as to what purpose the information is to be gathered. In an earlier era biological surveys of streams had the broad but single objective of measuring fish producing resources and determining how they could be managed to secure the best, continuing yield for fishermen (Lagler 1950). Today the need to raise thinking and action to the ecosystem level is especially evident in the practices of environmental impact analysis, instream flow

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needs identification, aesthetics and wildlife quantification, endangered and threatened species consideration, and user classifications. No longer can the fisheries biologist do his own thing, but instead must interface on a more interdisciplinary scale of meaningful dismemberment and restoration relative to a variety of stream problems, conflicts, and adjudications.

The second working principle emerges once the problem statement is developed and transposed to an objective, and that is the wherewithall for accomplishment rarely equals the task. In other words, there are always more problems, particularly in a holistic approach, than there are time, money, and bodies to solve them. This may have two important opposing effects. On the one hand, it favors reliance on the available information and resources of other disciplines and agencies (e.g., flow data of USGS) or system or holistic analysis by interdisciplinary teams advocated by Platts (1976). On the other hand, austerity can force efficacy through advanced planning--the selection and prearrangement of events for the predictable attainment of an objective (Phenicie and Lyons 1973). The danger of "cookbook" planning is that attainable, measurable objectives are usually narrow and not holistic in scope, leading to the impression that streams are a mere collection of water and not a biological entity.

Admittedly, data series by their nature tend to be exhaustive of observations made while inconclusive of principle or meaning to be drawn; yet, experience clearly demonstrates they do provide insight on ecological processes and events that were hardly considered during the years that the data were routinely collected (Reiger 1973). Odum (1977), in discussing the current charges of "boondoggle" and counter defense charges regarding environmental impact statements, points out that such mass produced checklist or data series assessment is not so much bad or inadequate science as it is wrong-level applied science. The emphasis is on the species or factor level when the questions and decisions clearly involve the ecosystem level.

The watershed has been increasingly recognized as the basic ecosystem unit involving streams or lakes (Dillon and Rigler 1975, Patric 1975). Fortuitously, fish are excellent "red flag" indicators, both of the land delivering the water to a stream and the stream channel itself. Accordingly, there is much to be said for zeroing in on a few carefully selected properties that monitor the performance of the whole, either by stream types or problem perturbations, while at the same time not overlooking the obvious. Stream surveys are not an end in themselves, of course, but a means to the end (Behnke and Zarn 1976) and that end should be anticipated, as best possible, in selecting from the wide array of survey techniques, methods, and tools available.

GOALS AND OBJECTIVES

Given the circumstances of our present national population size and distribution, as well as our life style and expectations, integrated social benefit can only be interpreted to lie in extending the utility of existing, finite water resources (National Science Foundation et al. 1974). This means that only in rare circumstances, if at all, are we going to be allowed the luxury of dealing with natural streams not subject to various uses and/or perturbations of man. Accordingly, we must develop the capability of maintaining ecological integrity, defined by Cairns (1977) as the maintenance of structure and function characteristic of that locale, or of replacing the indigenous with something of at least equal value. Within this framework, Gibbons and Salo (1973) have summarized the principal interests of land managers in stream information:

1. Development of stream classification systems that enable rational day-to-day management involving the elements of stream productivity, sensitivity to disturbance, watershed geology and composition, and fish producing capabilities and standing crop.

2. Development of deterministic models, relying on case history studies and ecological principles, in answering specific questions in planning, including instream flow needs.

In stream surveys there has been some tendency for federal agencies to concentrate on the physical habitat while state fish and game agencies are responsible for fish or biological aspects. They are inseparable, of course.

The dichotomy between the abiotic and the biotic is illustrated by methods developed in establishing instream flow needs. Field methods range from detailed analysis of an entire stream to aerial surveys, the most common method being transect analysis. Variations in transect analysis are as numerous as the number of users (Orsborn and Deane 1976, Stalnaker and Arnette 1976). Much of their appeal lies in the use of physical facts that

lend themselves to mathematical treatment. Where criteria are available, e.g., spawning and rearing flows for salmonids, good relationships between potential instream resource quality and flow level can be developed. The point of flow recommendation and establishment is where the analysis fails to provide the type of information needed. One or two flow levels, or even a range of flow levels, without some sort of an instream production function is of limited value for evaluating alternative management policies (Orsborn and Deane 1976). In the real world monetary values based on a production function have (e.g., beneficial use aspects of Western water appropriation law, Stalnaker 1977) and will continue to weigh heavily in the decision making.

Biotic surveys often lack the high degree of specific detail found in abiotic surveys. Moreover, the data is less subject to determinate mathematical treatment due to multiple variables and interactions of living systems. The key to the assessment of a production function between the physical habitat and fish population is knowledge of the taxonomy, dynamics, and interactions of the fish stocks and related fauna. Such knowledge derives from the study of captured specimens. In most methods of capture, the problems of sampling error and bias in respect to gear, community developmental status (Hunt 1976), and spatial considerations are staggering, with reconciliation largely subjective.

It is perhaps inevitable to look to science for fact alone in solving problems, but it also should not be overlooked that only man, in the light of prevailing values and circumstances, can provide meaning from facts.

TOOLS AND TECHNIQUES

The tools available for fish sampling are almost endless; electro-fishing, nets, chemicals, explosives, creel census, visual observations (underwater and aerial), hook-and-line, etc. All have their uses and biases.

Development of electro-fishing over the last thirty years has allowed sophisticated understanding of trout ecology in small streams (generally $\leq$ 25 cfs) Heacox 1976, Hunt et al. 1962, McFadden 1961. Similarly effective tools for sampling larger streams are needed. In the meantime, however, the practice of the new ecology could be benefited by more innovative use of existing tools, much as efficacy was augmented by the new mathematics of recent years. Not to be overlooked is that primitive seines were used in Allen's (1951) classic trout population study of the Horokiwi Stream.

In addition, interdisciplinary problem solving, while increasing the information base, involves much valuable, but nonsystematic information not widely available, e.g., in the minds of the practitioners (Stalnaker and Arnette 1976). Codification of instream flow methodologies received a major boost with the Instream Flow Needs Symposium and Speciality Conference, sponsored by the Western Division of the American Fisheries Society and the American Society of Civil Engineers, held only in May, 1976. Since that time the Fish and Wildlife Service's Cooperative Instream Flow Service Group, a multiagency, multidisciplinary entity has come into being and furthered development, codification, standardization, and acceptance of integrated stream assessment. Most significantly IFG has refined the Bureau of Reclamation's promising Water Surface Profile modeling and incorporated biological criteria, subject to rigorous deterministic treatment, capable of identifying production functions.

Of course not all streams warrant such detailed treatment, but the goal of quantitatively relating the abiotic to the biotic should not be lost sight of even in reconnaissance level assessment. Platts' (1976) work in the 397 square-mile Idaho Batholith illustrates the frustrations of such a goal. Fish populations were removed from 2.75 miles of stream, encompassing 291 stations, using four miles of explosive prima cord. Multivariate analysis incorporating physical data from 2,482 habitat transects (Herrington and Dunham 1967) of the twenty-eight streams sampled failed to demonstrate strong correlation with standing crop. Despite the lack of correlation between variations in the fish populations and variations in habitat, the fish standing crops were still the most revealing measures of the streams inventoried. In other words, I don't believe anyone would disagree that such information as developmental status of the aquatic communities, presence or absence of rare and endangered species, lack of pollution, relative productivity, etc., are not essential to baseline assessment. It is this property of indicating past environmental condition, especially the extreme conditions of brief duration, that make the presence or absence of aquatic populations such valuable "red flag" indicators of habitat.

Collatzi (1976), by contrast, completed 200-300 habitat transects (Herrington and Dunham 1967) on 154 trout streams (964 miles) involving one million acres of forest lands

in Utah and Wyoming in developing sensitivity to disturbance criteria for valley lands needed in protecting instream values. The results might have been much more meaningful had it been possible to have identified a production value for a subsample of the habitat transects, say with sampling using sodium cyanide (e.g., one-ounce tablet in a brushy stream with a flow of one cfs, two men collected and released eighty-four brown trout within one hour, personal communication, Robert Wiley, Wyoming Game and Fish Department; also, see Wiley et al. 1975). Again we see the problems and restraints in addressing the ecosystem level.

Events and circumstances tend to eclipse the usefulness of much of the species and factor detail gathered in routine surveys, except for observations of fish populations as indicators of habitat. Not infrequently even the latter is "lost." A case in point is the Bureau of Reclamation's (1975) trout habitat study on the Strawberry River below Soldier Creek Dam, Utah. The assessment pertained to a controversial minimum flow. Options were innovatively and conclusively identified using a variety of tools and methods, except that the fish production function tended to be more qualitative than quantitative. The field leader corrected this deficiency with an ocular estimate of the trout present in selected sections of the stream (personal communication, Susan Pidge, Warburg, Alberta). In this small, clear stream such careful observation was perhaps as good a method as any other available, but eyeball appraisals currently have little scientific credence unless the practitioner is clad in a wet suit.

An even more obvious consideration is that the fisheries biologists should not become preoccupied with establishing "preservation flows" below a proposed point of diversion in a stream. Any water withdrawal implies a change in regime, followed by a change in morphometric factors, and ultimately a new rate of scour and the rate of deposition. Logically, major effort should be directed toward evaluating the ecological effects of predicted new flow regimens (Stalnaker 1977).

Readily-measured keys to understanding, predicting, and modifying stream fish populations are yet to be perfected, although long sought by fisheries biologists with fair success in ponded waters (Jenkins 1967, McConnell et al. 1977). Although standing crop is a fairly good estimator of "fertility" in respect to growing fish crops, and does not necessarily bear a close relationship to actual fish production (Carlander 1955), it would not seem essential to have such information except for representative streams. An adjunct or substitute estimator of nutrient supply in streams is electrical conductivity. Although widely used in agriculture (California Fertilizer Association 1975), fisheries biologists appear to have overlooked the merits of this measurement. Lennon (1959) first called attention to the possibilities of electrical conductivity in fisheries work. It is easily and accurately replicated, reflects gross ion concentration, and in non-turbid, fresh water is the reciprocal of total dissolved solids, demonstrated by Jenkins (1967) as exerting the greatest positive influence on fish crops in reservoirs.

Only when the fish production bounds of the water itself is established is it possible to proceed in a rational manner in identifying factors, if any, inhibiting or constraining that potential. Much of the routine procedure that has grown up and been adopted for stream surveys are of little value in such analysis. An example is the elaborate ritual (e.g., Lagler 1950, ". . . standing in the stream with back to the sun, holding the thermometer at forearms's length . . . .") in the determination of a water temperature. While no one can fault temperature as a primary ecological regulator in streams, the value of one or a few random readings as an indicator of temperature conditions prevailing during the life history of the organisms comprising the population can be questioned. Inasmuch as it is extremes of temperature that limit certain groups of organisms, information content of temperature data can be increased manyfold by recordation of temperature extremes with an uncomplicated and inexpensive maximum-minimum thermometer over a diurnal, seasonal (critical winter or summer), or annual cycle.

Averages of dissolved oxygen concentrations determined from grab samples are of little value and may be actually misleading. By measuring dissolved oxygen over diurnal cycles, the balance between the two major metabolic processes, photosynthesis and respiration, can be determined. Likewise, arranging volume of flow data into a flow duration curve or species data into a diversity profile provides a far better basis in judging the extreme and not the average conditions which are important.

In conclusion, almost all tools, methods, and observations can be worthwhile in stream surveys and are essential in many instances. Nevertheless, their adequacy and usefulness could be increased manyfold, at little or no added cost, if a more innovative systems-level approach were adopted, tailoring tools and techniques to perceived needs, rather than cookbooking in response to vague impetus.

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Current Rangeland Inventory Methods — Compatability Toward an Ecological Base?[1]

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Abstract.--Current rangeland inventory techniques used, or proposed for use, by the Forest Service, Soil Conservation Service, and the Bureau of Land Management are reviewed. Description of cover type mapping criteria, inventory units, minimum parameters for inventory and analysis, production-utilization estimate methods, and rangeland condition-trend determination used by each agency are given. Intra- and inter-agency inventory coordination and the concept of an ecological data base are discussed.

INTRODUCTION

Congressional legislation has recently set mandates for renewable natural resource inventories requiring agency cooperation and coordination to achieve inventories that are cyclic, continuous, and updateable. To be meaningful, these inventories must have data bases which allow aggregation and disaggregation for optimum program direction and management decisions at various levels of planning and management.

Resource inventories are not new, but the demand for inter- and intra-agency coordination brought about by Congressional mandate and increased public awareness has developed a sharpened sense of effectiveness in inventorying our dwindling and often abused renewable resources. Functional system inventories and reinventories are being strengthened to include other system parameters to avoid duplication and base differences.

This paper includes and interprets some of the current rangeland inventory methods used or proposed for use by the USDA Forest Service, USDA Soil Conservation Service, and the USDI Bureau of Land Management.

NEED FOR INVENTORY

Resource inventory is a prerequisite for program direction and management decisions throughout all resource systems whether at the local, regional, or national level. Informed decision-making requires inventories and update (monitoring) to determine the kind, areal extent, quality, quantity, and juxaposition of resources. Inventories are necessary also to develop the interactions of demand and supply, and cause/effect relationships between and within resource systems.

National resource assessments have been developed by the Forest Service (1975) using traditional resource systems of timber, range, wildlife/fish habitat, water, and outdoor recreation/wilderness. Continuing assessments will account for multiresource use interactions. To accomplish assessments that address resource interactions, vegetation and soils information must be collected and analyzed in a manner that is responsive to functional systems. To do this, one must realize all systems are interactive and the components of one system may be related to and accounted for in other systems. Therefore, if inventories are done on a strictly functional basis, "double counting" will occur within some system components. Other components of the system may not be counted. This will be dependent upon inventory requirements of the system for which the estimates are obtained.

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LEGISLATION AFFECTING INVENTORY

Recent Congressional mandates have an important affect on the need for and requirements of coordinated multiresource inventory systems and bases. These Acts are the: (1) Forest and Rangeland Renewable Resources Planning Act of 1974 (FS/RPA; PL93-378), (2) National Forest Management Act of 1976 (FS/NFMA; PL94-588), (3) Federal Land Policy and Management Act of 1976 (BLM/Organic Act; PL94-597, and (4) Soil and Water Resources Conservation Act of 1977 (SCS/RCA; PL95-192).

The common themes of these Acts are: (1) to prepare and maintain continuous resource inventories, (2) coordinate and cooperate with other resource agencies and organizations to avoid duplication of inventory and planning efforts, (3) determine the changes in status and condition, both current and potential, of the resource base, (4) determine resource interactions and management alternatives, and (5) submit periodic assessment reports.

These Acts imply that inventories be made at site-specific locations (intensive) to address local management needs. At the same time, broad area inventories (extensive) will address large planning areas which have not yet been surveyed. Extensive inventories will also address areas where adequate base data is available and only monitoring is necessary. At any level of intensity, inventories derived from compatible classification systems, sound ecological bases, and common definitions are a must for aggregating and disaggregating data to and from National level assessments for program direction and management.

If non-functional data forms the inventory base, (i.e., soil,vegetation, and water) then a truly ecological system should address all functions in an interactive system. One of the prerequisites for an ecological data base is inter- and intra-agency method compatability. Compatible inventory methods, standards, and definitions would allow data to be combined for evaluating resource interaction, management alternatives, and National statistics. It should also avoid duplication by different agency functions inventorying the same piece of landscape.

RANGELAND INVENTORY

In response to the RPA and the need for multiresource inventories, a Research and Development Program was established at the Rocky Mountain Forest and Range Experiment Station with nationwide responsibility for development of resources evaluation techniques. This Program is described by Aldrich (this Proceedings).

Prior to modifying, combining, or developing new techniques for multiresource inventories, it is necessary to know and understand what is currently being done within and between agencies. The purpose of this paper is to examine those rangeland inventory systems currently being used or proposed by the FS, BLM, and SCS. It is also necessary to define what rangeland means in both ecological and use-oriented terms.

Ecologically, rangeland is that land on which the native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs or shrubs. Included are lands revegetated naturally or artifically to provide a vegetation cover that is managed like native vegetation. Rangelands include natural grasslands, savannahs, shrublands, most deserts, tundra, alpine communities, coastal marshes and wet meadows (adapted from Soc. Range Manage. 1974). Range embraces rangelands and also many forestlands which support an understory or periodic cover of herbaceous or shrubby vegetation amenable to certain range management principles or practices (Soc. Range Manage. 1974). The definition of range is use oriented and does not include other uses made of rangelands.

Forest Service (FS)

National

The Forest Service administers approximately 55.6 million acres occurring within 15 rangeland ecosystems; additional forest-ranges occur within several forested systems (U.S. For. Serv. 1975). The general guidelines for mapping, inventory, and analysis of these lands are established by the Forest Service's Washington Office (U.S. For. Serv. 1968; table 1). Regional Foresters develop more specific standards and guides for inventory and analysis. Eight broad vegetation cover types are the minimum to be used for mapping (table 2).

The range allotment has been designated by the Washington Office as the basic interpretative unit (table 3). Within the allotment, several parameters are inventoried including vegetation cover type, apparent and long-term trend in condition, and production-utilization (table 4). Aerial photo scales of 1:20,000 or larger are recommended for mapping (table 2). The 3-step method is recommended for determining long-term trend in range condition. By using this method, frequency is obtained by recording perennial

Table 1.--Rangeland procedural handbooks

Agency	Handbook Title	Date	Status
Forest Service... National	Range Environ. Analysis and Studies...FS Manual 2212	7/68	Periodic Amendments
Forest Service... Regional			
R1-Northern	Range Analysis	4/77	Reissue/Revised
R2-Rocky Mountain	Range Environmental Analysis	11/68	Periodic Amendments
R3-Southwestern	Allotment Analysis	1977	Reissue/Final Review Draft
R4-Intermountain	Range Environmental Analysis	3/69	Periodic Amendments
R5-California	Range Environmental Analysis	1/69	Periodic Amendments
R6-Pacific Northwest	Range Environmental Analysis	7/71	Only Mapping Chapter Completed-other Regional Guides
R8-Southern	Range Analysis Field Guide	9/76	Reissue/Revised
R9-Eastern	Range Inventory	2/77	None Previous/Proposed Draft of Inventory Chapter
R10-Alaska	---	----	No Handbook
Bureau of Land Management	Site Inventory Method... Manual 1731	4/77	Draft/Proposed
Soil Conservation Service	National Range Handbook	7/76	Revised/In Use

Table 2.--Aerial photo scale, minimum units delineated, and number of vegetative cover types used for mapping

Agency	Photo Scale	# Vegetation Cover Types Designated	Minimum Unit Delineated (A = # Acres)
Forest Service... National	>1:20,000	8 broad	
Forest Service... Regional			
R1	1:63,360	10 existing; habitat type if available	40A-broad 5A-meadows 1-2A-small parks
R2		11-on suitable range	40A
R3		13 broad; subtypes	40A >if needed
R4		12 broad	20A 5A-if needed
R5	use most up to date	14 types; subtypes on suitable range	40A 5A-meadows and high productivity areas
R6		12-present; potential if available	40A-dryland 5A-meadow
R8	1:15,840	26-on suitable range	20A 5A-wet meadow
R9		9 broad; subtypes	20A-broad 5A-subtype
R10		--No Handbook--	
Soil Conservation Service	1:31,680 1:20,000 or 1:15,840	described ranges sites; woodland suitability and native pasture groups	-locally determined -inclusions up to 15% -landscape dependent
Bureau of Land Management	1:24,000 or 1:31,680	19 broad; subtypes	6A inclusions < 10%

Table 3.--Basic inventory interpretative units

Agency	Unit: Description
Forest Service	Range Allotment: specific range area where administrative practices applied; established on basis of the kind and number of livestock, amount and availability of forage, and needs of other resources. (R6 uses plant communities or TRI System (U.S. For. Serv. R-6 1974) cells which are homogeneous divisions of the allotments)
Soil Conservation Service	Range Sites: used for rangeland; based on plant composition and production as major criteria for identification and description; ability to produce a characteristic natural (climax) plant community. Woodland Suitability Groups: used for grazeable woodlands; based on differences in total potential productivity, in dominant trees, or limitations for management or harvesting. Native Pasture Groups: areas used primarily for grazing, but ecological potential is trees; consists of one or more soils capable of producing similar kinds/amounts of trees and/or herbaceous vegetation.
Bureau of Land Management	Site Writeup Area: delineated on the basis of current vegetation aspect/cover/composition, erosion condition, soils.

Table 4.--Minimum parameters for inventory and analysis

Agency	Parameter
Forest Service	1. Vegetation cover type mapping 2. Range suitability for livestock 3. Apparent and long term condition and trend for vegetation and soils 4. Production/utilization for livestock and big-game 5. Grazing capacity and season for use for livestock
Soil Conservation Service	1. Potential vegetation 2. Physical environmental data. . . soils + others 3. Primary and secondary production; utilization 4. Monitor changes (condition and trend) 5. Range suitability, grazing capacity, and season of use 6. Economic information 7. Study, inventory, analyze, treat, and manage the above on an ecological basis
Bureau of Land Management	1. Inventory soils, terrestrial, and riparian vegetation 2. Present and potential vegetation composition, cover, production, community structure 3. Map soils and associated vegetation 4. Present condition and apparent trend 5. Sediment yield 6. Monitor change in base data for livestock and wildlife

plant species rooted within 3/4-inch circular plots systemically located along 100-foot transects (Parker and Harris 1959). Each Region is to develop criteria for using the 3-step method and guides with minimum data requirements for judging trend in condition on suitable ranges. It is recommended that trend measurements from benchmarks be made every 5-10 years depending upon vegetation type, climate, management practices, and other factors. The same phenological stage of plant development is required for benchmark remeasurements. Methods other than the 3-step may be used for periodic long-term trend if the methods are appropriate to the site and plant community. These supplemental methods are left to Regional discretion. Soil condition is associated with abundance and dispersion of plant cover (i.e., vegetation, litter, bare soil).

Herbage yields are used to evaluate site potential and vegetation condition. The method used (table 5) depends upon the kind of vegetation, inventory intensity, accuracy and precision, and available funds and personnel. Measurements of forage utilization by livestock and big-game are mandatory within suitable ranges. Five methods are recommended for use. These methods vary from ocular estimate by plot to grazed twig counts (table 6).

Regional

All FS Regions have at least partial range analysis handbooks except for Alaska (R-10) (U.S. For. Serv. R-2 1968; R-4, R-5 1969; R-6 1971; R-8 1976; R-1, R-3, R-9 1977). Most of the handbooks are complete, some have been revised, and most are being used in the field except for the Eastern Region (R-9) (table 1). The Pacific Northwest (R-6) handbook has only the mapping chapter completed, but it is supplemented by other Regional Guides which are either published or in preparation.

Aerial photos used for vegetative cover type mapping vary in scale between Regions (table 2). Two Regions specify the scale to be used, the others do not. Photo scale determines the minimum size unit that can be delineated depending upon the vegetation type, areal extent, homogeneity, film type, and scene contrast. Minimum unit size varies between 40 acres for broad, homogeneous units to 1 acre for small parks (table 2). There is also a wide variation between handbooks in the number of cover types to be delineated. The minimum is eight as set by the National standard (table 2). These eight broad types may or may not be recognized depending upon the geographic location or floristic provinces of the Region.

Regions that have on-going procedural handbooks use the 3-step method to determine long-term trend in range condition (table 7). Most of the Regions have retained the method for that purpose, but some have supplemental techniques for additional data gathering. For example, the Pacific Northwest Region (R-6) is discouraging the establishment of new 3-step clusters, but is rereading established clusters as needed. R-6 is also proposing permanent photo transects with plot estimates to replace, supplement, or superimpose on existing 3-step transects (Hall 1976).

Even though the 3-step method is used in most Regions, the criteria and standards for its use vary between Regions (table 8). For example, herbaceous plants are always recorded if rooted within a 3/4-inch loop, but standards for data recording vary if more than one species occurs within the loop. Annuals, seedlings, nearest plant information, and understory may or may not be recorded depending upon the vegetation type and/or Region. One consistent criteria is that any specific soil surface factor must occupy 50% or more of the loop to be recorded if no plant is encountered. If there is no plant within the loop and a soil surface factor is recorded, four Regions record nearest plant information, but the area from which that information is collected varies.

Vigor is a criteria for condition and trend within all Regions. Leaf length of the key species is the most commonly measured attribute for rating vigor. Color, size, and total plant height are also vigor attributes measured or qualitatively estimated by some Regions (table 8).

In addition to the 3-step method, paced-transects are used by all the Regions for apparent condition and trend. These transects may use toe-point, paced-loops, or variations of the 9.6 square foot plot (table 7). The Northern Region (R-1) specifies the use of 35-mm color infrared aerial photos of selected locations. These photos are used with 100-point transect overlays to estimate ground attributes similar to those estimated with the 3-step procedure. In the Eastern Region's (R-9) proposed procedural handbook, either permanent or paced transects with photo points or plots are required for condition and trend estimates rather than the 3-step method. Two other Regions also call for ground photo plots other than those used in the 3-step method (table 7).

All Regional handbooks include range suitability classification and production-utilization estimates. The methods and criteria for determining these parameters vary between Regions. For example, suitability may or may

Table 5.--Vegetation production estimate methods

Agency	Method
Forest Service*	
Natl., R1-R3, R8	Ocular estimates 0.96 or 9.6 sq. ft. plots 10-20 plots per transect or or unspecified
Natl., R1-R3, R8	Actual weight paired or unpaired 3.1, 4.8, or 9.6 sq. ft. plots 10-30 plots cages per transect or unspecified clipping standards vary
R1, R2, R4, R9	Double sample caged or uncaged 0.96→9.6 sq. ft. plots plots in 5's; 2 caged: 8 uncaged; 10-30 plots per transect; or unspecified
R1	Herbage meter 30 plots per transect; 1 clip: 5 meter
Soil Conservation Service	Actual weight 1.92→9.6 sq. ft. plots for herbaceous 0.01→0.1 acre plots for shrubs and trees nested if vegetation mixed 10 or 20+ plots Double sample as per actual weight Weight units as per actual weight
Bureau of Land Management	Herbaceous weight units 0.96→9.6 sq. ft. plots 10+ plots Shrub characterization plots 0.01 or 0.02 acre circular or rectangular 10+ plots

*R10 not included.

Table 6.--Vegetation utilization estimate methods

Agency	Method
Forest Service*	
Natl., R1-R3, R6, R8	Ocular estimate % by weight or use 0.96 or 9.6 sq. ft. plots 10-20 plots per transect or unspecified
R3, R5	Appearance guides standard photo comparisons unspecified number of check locations

*R10 not included.

Table 6.--(Continued)

Agency	Method
Natl., R1, R5, R8	Actual weight 9.6 sq. ft. paired plots Clipping standards vary; ground level to 1" stubble height
Natl., R1-R9	Counts # plants or plots grazed or ungrazed; % weight or removed or % use 3"-5" loop, or 0.96→9.6 sq. ft. plots 100 pt. pace transect or unspecified
R2, R5	Height-weight curves % weight grazed plots or pace 1 or mor 50 pace transects 10-50 samples per species
	Shrubs (Browse)
Natl., R1-R5	Form/age class Tagged or untagged twig, branch, or plant 1 species per transect or unspecified ranked-set, circular, or belt plots Pellet counts relative area use 1/100 acre belt or circular plots; 3' x 3' plots; 5' x 10' chain plots; or unspecified
Soil Conservation Service	Herbaceous Ocular estimate % removed unspecified number of plots Appearance guides grazed classes unspecified number of plots Weight units weight grazed vs. ungrazed Shrubs (Browse) Form/age class Reproduction Others
Bureau of Land Management	Herbaceous Weight units 0.96→9.6 sq. ft. circular or rectangular plots minimum of 10 plots Shrubs Shrub characterization plots 0.01 or 0.02 acre circular or belt plots minimum of 10 plots leader length, form/age class, height, crown diameter/cover pellet counts (relative area use)

Table 7.--Methods used for determining rangeland condition and trend

Agency	Method
Forest Service*	
Natl., R1-R8	Three-step transects (3/4" loop) Permanent for long-term conditions and trend
R1-R8	Paced transect Toe-point, paced 3/4" loop, or 0.96 ⟶ 9.6 sq. ft. plot Ocular estimate Apparent condition and trend
R1, R6, R9	Ground photo plots (other than 3-step -hotos) R1--grid with 3/4" loop R6--permanent photo trend transects R9--permanent or paced transects with photo points or plots
R1	Aerial photos 35 mm CIR with 100 pt. transect photo overlay
Soil Conservation Service	Ocular estimates Apparent trend Harvest plots Double sample; spp. dry weights
Bureau of Land Management	Paced transect Notched boot Harvest plots Double sample; spp. dry weight

*R10 not included.

Table 8.--Three-step method criteria used by Forest Service Regions

Agency	Attributes recorded and criteria
Forest Service*	
All Regions	Number of transects per cluster < 30 hits = 3T, 31-60 hits = 2T. > 61 hits = 1T
All Regions	Perennial herbaceous R1, R4, R6 > 1 spp. hit, proportion hits R2, R3 > 1 spp. hit, record dominant spp. R5, R8 > 1 spp. hit, record most desirable spp.
All Regions	Annual herbaceous R5 Recorded as hits R1 Recorded separately as least desirable R2, R4, R6 Record as litter hit; R6 dot tallies important spp. R3, R8 Ignore live, dead as litter; R8 records relative abundance
R1, R4	Perennial seedlings
All Regions	Surface factors If not plant hit; > 50% of loop
R1, R3, R6, R8	Nearest plant occurrence If no perennial spp. hit Variable plot size and location
All REgions	Overstory Perennial shrub and tree crowns ≯ 5 ft. high
R1-R5	Understory R1, R2, R3 If overstory is alive or dead R4, R5 Only if overstory dead R1, R2, R4 Summarize only if overstory dead R3, R5 Ignore in summary
All Regions	Vigor
for key species	R1-R6 Leaf length R8 Seed stalk length R2, R5, R6 Color, size, height

*R10 not included; R9 does not specify 3-step.

not be based upon the number of pounds of forage per acre. Production-utilization sampling methods vary from ocular estimates to actual harvest depending on the objectives and/or survey intensity (table 5 and 6). The use of the herbage meter (Neal et al. 1976) is prescribed by one Region. All FS Regions require utilization counts. These counts may be the number of plants or plots grazed and/or ungrazed; or the percent used or weight removed. Two Regions prescribe the use of height-weight curves for utilization estimates. These curves may be for specific species, or may be for broad vegetation types such as wet or dry meadows. Standards have been developed which use height-weight curves for key species rather than broad classes. For example, within the California Region (R-5), culm length of key wet mountain meadow herbaceous species have been measured. The percent weight removed may be determined from height-weight tables according to height class by species (McDougald and Platt 1976).

Five Regional handbooks specifically address production-utilization estimates for shrubby (browse) species (tables 5 and 6). The most commonly prescribed method is plant form and age class. Relative intensity of animal use within an area is obtained from fecal counts. Plot designs vary and may be circular, belts, or nested and are usually 1/100 acre in size.

Species composition is an important attribute of condition and trend determinations and other parameters. Composition is primarily obtained from permanent or paced transects generally using criteria established for the 3-step method.

When collected, detailed soils information is usually compiled by soil scientists. Soil mapping may or may not be completed prior to vegetation mapping and sampling. Regions 5 and 6 emphasize the use of soil pedon information for condition-trend determination, including a soil pit, profile description, and subsequent classification. Soil and vegetation condition are usually rated separately by all Regions. The lower of the two ratings may be used for the overall condition rating.

Soil surface factors are collected in each Region to determine erosion hazard index, current soil erosion, soil condition and trend, and soil surface cover. The information collected includes bare soil, litter, pavement, gravel, and rocks. Plant cover is used also in the estimation of erosion potential, and soil condition and trend. As mentioned previously, soil surface factors are recorded only when no perennial herbaceous plants are rooted within the loop when using 3-step criteria. If a surface factor is recorded according to those criteria, only that factor occupying the majority of the loop is recorded and other factors ignored. Surface factors occurring as shrub understory may or may not be recorded and/or summarized.

Soil Conservation Service (SCS)

National

The SCS has primary responsibility for conducting resource inventories and soil surveys on non-federal lands. The National Range Handbook (USDA, Soil Conserv. Serv. 1976) details the goals, practices, and procedures for conducting and applying the results of those resource inventories on native grazing lands. These procedures implement an ecosystem approach to conservation on rangeland, grazeable woodland, and native pasture. The interpretative units of these three categories are range sites, woodland suitability groups, and native pasture groups (table 3). These units provide herbage for livestock and/or wildlife.

SCS inventory objectives emphasize use by livestock, but essentially address all resource functions through intensive measurements that provide ecological information and a basis for monitoring changes (table 4).

Primary productivity and plant composition are the major attributes used to identify and describe the interpretative units of native grazing lands. The interpretative units are delineated on aerial photos using locally determined photos scales of 1:15,840, 1:20,000, or 1:31,680 (table 2). The minimum size unit is also locally determined. Inclusions of up to 15 percent are allowed. The resultant delineations based on vegetation and soils data are classified into previously defined and described interpretative units. Current vegetation on range sites is an expression of the relative degree of departure from the presumed climax or potential vegetation.

Production estimates are obtained by using actual weights or weight unit estimates (table 5). For example, actual weights may be obtained by clipping every plot or double sampling. The plot size may vary from 1.92 square feet on homogeneous, relatively dense vegetation to 0.1 acre if the vegetation consists of trees and large shrubs. If the vegetative life-forms are mixed, plot size and shape may be nested. The number of plots is determined by vegetation density and homogeneity. From these production measurements, species composition is determined from total annual production. Composition and production are the major criteria for classifying inter-

pretative units. The primary supplemental information used to describe interpretative units is soils, topography, and climate. Plant association tables coupled with these items may be used to identify similarities and differences between interpretative units.

Utilization may be measured or estimated. Ocular estimates, weight units, or appearance guides may be used (table 6). For example, appearance guides use photos or written standards to place the interpretative unit into grazed classes. Utilization measurements are made on key species in key grazing areas. Browse utilization is usually estimated by form, age class, and reproduction along with other attributes.

The SCS determines condition, especially rangeland condition, by comparing existing plant communities with presumed climax described for the site. Sites are differentiated on the basis of differences in production and the kind, proportion, and amount of plant species regardless of their value for forage. The data for comparison is obtained by sampling the current vegetation using species dry weights.

State

SCS State Conservationists issue technical guides for native grazing lands using the basic procedures given in the National Range Handbook (NRH). Using the NRH for methodology and sample criteria, the state technical guides give more detail for sampling specific interpretative units.

State guides contain standards for: (1) evaluating potential by identifying and describing interpretative units, (2) determining conditions and assessing forage value ratings, (3) developing specifications for conservation practices, and (4) selection and application of conservation practices. These guides do not alter the prescribed inventory procedures outlined in the National Handbook (Merkel 1977).[3]

Bureau of Land Management (BLM)

National

The BLM is responsible for the multiple use management of 168 million acres of land in the contiguous 48 states (U.S. For. Serv. 1975). These lands include approximately 140 million acres of rangeland, 24.5 million acres of noncommercial forest land, and 3.5 million acres of commercial forest lands. BLM currently administers an additional 283 million acres of land in Alaska.

Extensive rangeland inventories utilizing the ocular-reconnaissance method have been conducted since 1934 on the western rangeland. Guidelines, procedures and study methods are contained in BLM manual 4412 (USDI Bur. Land Manage. 1968).

A more detailed resource inventory system is now being developed by BLM (table 1). The "Site Inventory Method" (SIM) is designed to inventory soils, terrestial, and riparian vegetation (USDI Bur. Land Manage. 1977). This method will establish a data base for management decisions concerning current and potential use in resource planning, management, and environmental statements. The procedures propose a uniform, systematic method for the inventory of soil and vegetation resources and wildlife data. Specific wildlife habitat information will be obtained through the proposed "Integrated Habitat Inventory and Classification System" (USDI Bur. Land Manage. 1976).

The SIM handbook addresses the parameters of both current and potential vegetation, present condition, apparent trend, and monitoring of change (table 4). SIM is proposed as the official agency wide inventory method, but does not preclude more specific site studies for special purposes. The basic interpretative unit of SIM is the Site Writeup Area (table 3). The Site Writeup Area may be delineated to a minimum size of 5 acres with vegetation or soil inclusions of up to 10 percent on aerial photos using a standard scale of 1:24,000 or an alternative scale of 1:31,680 (table 2).

Soil mapping units with unique characteristics may be delineated to 6 acres; smaller areas are identified by spot symbols. The mapping units are usually consociations, associations, and complexes of soil series or phases of series. Undifferentiated delineations are used if areas containing 2-3 similar soils support the same potential vegetation. Delineations are transected several times on the ground to provide valid and accurate soil boundaries and identification.

Vegetation species composition within the Site Writeup Area is obtained by using a 200-point pace transect which usually traverses the longest axis of the area. If more than one soil phase occurs per vegetation association, the areas are proportioned and sampled separately. Vegetation and soil surface factors

[3]Merkel, D. L. 1977. Personal communication. SCS Range Conservationist, USDA For. Serv., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

are sampled using a 1/8-inch x 1/16-inch notch on the toe of the examiner's boot. If two or more items are in the notch, the item recorded is that which occupies the majority of the notch. If the area is equally occupied, a sequence of five preferred identifications is followed with vegetation being the most preferred and stone being the least. The occurrences are not proportioned; overstory is recorded.

Plots are established at every twentieth point along the transect and are used to compile data on: (1) vegetation condition, form, age, availability, and utilization, (2) production weight and number of plants by species, and (3) fecal counts by animal species. The plots may be circular or rectangular variations of the 9.6 square foot plot with size and shape depending on the homogeneity and density of herbaceous vegetation. Shrubs are measured using either 1/100 or 1/200-acre circular plots or belt transects. The size of these "shrub characterization plots" is dependent upon the density of the shrub stand (tables 5 and 6).

If the Site Writeup Area includes a tree type, "forestry plots" are established in addition to the weight estimate and shrub characterization plots. Two concentric circular plots with radii of 11.7 and 37.2 feet are established at each weight estimate plot center. At least three dominant or codominant trees in each site are measured. Data recorded includes species, age class, DBH, and height. Erosion condition class is also estimated for each site.

Information on aquatic, wetland, riparian, and terrestrial wildlife/fish habitats and animal species occurrence is recorded. Included is information on flowing and ponded waters, stream bank ratings, submergent and emergent vegetation, emphemeral and perennial wetlands, production-utilization, plant species composition, and soils.

State

The SIM Handbook is designed to provide a uniform BLM approach to the inventory of soils and vegetation with supplemental information about wildlife/fish habitat and animal species occurrence. BLM State Directors may issue more specific directives and technical guidelines to supplement and implement the basic SIM Handbook. As a part of the development of the SIM procedure, modifications are being suggested and tried (Hagihara 1977).[4]

COMPATIBILITY TOWARD AN ECOLOGICAL BASE?

In this paper, rangeland and range were defined to gain a common understanding of one functional resource system. The need for inventory and the recent legislative mandates that affect inventory by agencies have been discussed to form the background for an outline of the current rangeland inventory methods used or proposed for use by the FS, SCS, and BLM. The agencies are required to coordinate and cooperate in developing periodic and continuous inventories and assessments of the Nation's natural renewable resources. In conducting these inventories, the agencies are to avoid duplication of efforts. They are to address compatible bases for data aggregation and disaggregation. But will they?!

The FS procedural guides are oriented toward livestock, but do include some wildlife and other resource considerations. Even though the philosophy and techniques adopted by the FS are oriented toward an ecological base, the data collection and analysis criteria are variable between Regions. This variability makes it difficult to combine, analyze, and interpret the data for some parameters.

The BLM and SCS are using similar philosophy, approaches, and methods to inventory the rangeland resource. The prescribed or proposed methods approach an inventory that takes into account not only range and rangeland attributes, but attempts a total profile of any particular interpretation unit. This allows for some data manipulation, analysis, and interpretation to fit the needs of several resource functions and forms the framework of an ecological base. However, the proposed BLM Site Inventory Method and the SCS National Range Handbook do not provide for permanent benchmarks to make long-term evaluations of trend in condition. Both agencies emphasize the need and objective of monitoring the data base for change. The SCS uses periodic area remeasurement for changes in condition class of range sites to determine long-term trend. The SIM procedure emphasizes continuous studies to monitor the data base. Also used are comparison areas, which are essentially SCS range sites to establish the potential and condition class of BLM Site Writeup Areas.

If an inventory of the basic resource components (soil, vegetation, water) can be made

[4]Hagihara, J.S. 1977. Personal communication. BLM Research Coordinator, USDA For. Serv., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

that addresses the major needs and requirements of all resource systems, then an ecological base has been approached. The various base data can then be combined to serve all resource systems and interactions between those systems.

Developing an ecological base requires intra- and inter-agency coordination and cooperation within at least one resource system, such as rangeland. To have SIM applied effectively requires BLM State agreement and to have FS Regions compatible requires standard criteria for using the FS procedures. For example, FS Regions should standardize and agree that the 3-step method is primarily for plant frequency and not other plant attributes (Francis et al. 1972). Standard procedures for interpreting trend in condition from 3-step data (Reppert and Francis 1973) should be established. Morris (1973) describes a crosswalk between the standard 3-step and rated loops that would provide a more complete and quantitative sample. This procedure would also provide re-evaluation of benchmark areas that have been established for over 20 years.

Other inventory and analysis considerations such as sample intensity and design, accuracy and precision standards, classification systems, standard definitions and condition scorecards, harvest height standards and the season, frequency, and priority of inventory have not been mentioned in the context of this paper. All these items affect the inventory and analysis process for obtaining meaningful and reliable data for aggregation between and within agencies.

Legislation has provided the inventory mandates, now it is up to the agencies to provide commonality within themselves and compatibility between themselves. A step toward compatibility is an ecological rangeland inventory, not a use-oriented range inventory.

ACKNOWLEDGEMENTS

This paper is an interpretation of the rangeland inventory procedures of the Forest Service, Soil Conservation Service, and the Bureau of Land Management. Due to space restrictions, it was not possible to include all existing procedures used by the agencies reveiwed.

Appreciation is extended to those persons within the FS, SCS, and BLM who provided information. Apologies are extended to those agencies not reviewed within the context of this paper--their efforts are being included elsewhere.

I'll look forward to any feedback. We're all in this together.

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Inventorying Small Streams and Channels on Wildland Watersheds[1]

Robert L. Beschta[2]

Abstract.--The physical characteristics of small wildland streams can be inventoried using standard geomorphic techniques. These include characteristics of bed and bank materials, transverse profiles, channel gradients, drainage densities and stream orders.

INTRODUCTION

In recent years there has been a growing awareness by natural resource managers that small streams are an important consideration in land use decisions. Management practices which affect a watershed's characteristics can also influence the physical, biological and chemical qualities of a stream and channel environment. The hydrologic cycle provides an important linkage between land use and resultant changes in the dynamics of wildland streams.

Within this cycle a portion of the precipitation falling on a watershed eventually reaches a channel system through a variety of pathways and processes. Management practices can significantly alter the processing of precipitation inputs and thus affect the fluvial hydrology of wildland watersheds. The magnitude of change expected varies depending upon the intensity of a disturbance, its areal extent and its proximity to the stream and channel network.

The fact that land use activities such as road construction, timber harvesting, slash disposal, recreation use, grazing, mining activities and others can substantially alter the water resource is well documented throughout the literature. It is also shown that the severity of impact to a stream or channel can often be controlled through the application of sound management principles. Therefore, quantitative information of the stream and channel system is becoming increasingly necessary. Once a stream inventory has been completed it should provide a rational basis for evaluating management alternatives and assessing impacts. This paper will outline several types of characteristics that can be determined for wildland streams and channels.

Small streams which drain alpine, forested or desert landscapes have a significance much greater than their immediate on-site water resource values would indicate. Herein lies one of the important aspects of wildland streams; they largely control the quantity, timing and quality of water available to downstream municipalities, industry, agriculture and instream needs. Because of the hierarchial positioning of small streams in relation to the larger stream system, any changes in the characteristics of headwater streams or channels may ultimately be reflected throughout downstream reaches.

As defined by Webster, an inventory is an "itemized list"; in this case an itemized list of stream and channel characteristics. Instream monitoring may provide additional information about a particular stream system. To monitor a small stream involves measurements over time of channel characteristics, streamflow or water quality variables. Whereas inventory techniques can account for the spatial variability in a stream's characteristics at a specific point in time, monitoring techniques are used to evaluate temporal variability. In this paper, inventory techniques will be emphasized.

THE STREAM AND CHANNEL SYSTEM

Bed and Bank Materials

The characteristics of a stream bed and banks are an important factor influencing stream morphology and sediment transport. These surfaces provide frictional resistance to flow and are comprised of rock and sediment particles, vegetation and organic debris.

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The inorganic particles comprising a stream bed and bank can be classified in several ways. These include particle size distributions, particle shapes and mineralogy. In some situations the mineralogical composition of sediments can provide valuable information concerning sediment sources or the way particular rocks and minerals react to transport by fluvial processes.

Mechanical analysis of channel materials by sieving can be used to obtain particle size distributions (fig. 1). However, these cumulative frequency curves are not easily compared from one sample to another. Thus, median grain sizes or a ratio of percentages for selected grain sizes may provide a more appropriate comparison (Klingeman and Milhous 1970). Bed and bank material samples can be obtained by inserting a cylinder into the streambed or bank and retrieving all sediments within the cylinder. When sampling stream bed materials there is the possibility of losing substantial amounts of bed fines with this procedure. As an alternative, frozen core methods (Walkotten 1973) can be used to obtain undisturbed bed samples.

When stream bed and bank particles are generally greater than 5 mm in diameter a "pebble-count" may be used to identify the composition of channel materials (Leopold, Wolman and Miller 1964). A grid pattern is established (by pacing, survey points, or at specified intervals along a measuring tape) and the particle size determined at each point. Approximately 100 pebbles should be sampled to obtain reproducible results. This number of pebbles also makes the computation of cumulative percentages and plotting particle size distributions in the field extremely easy (Wolman 1954).

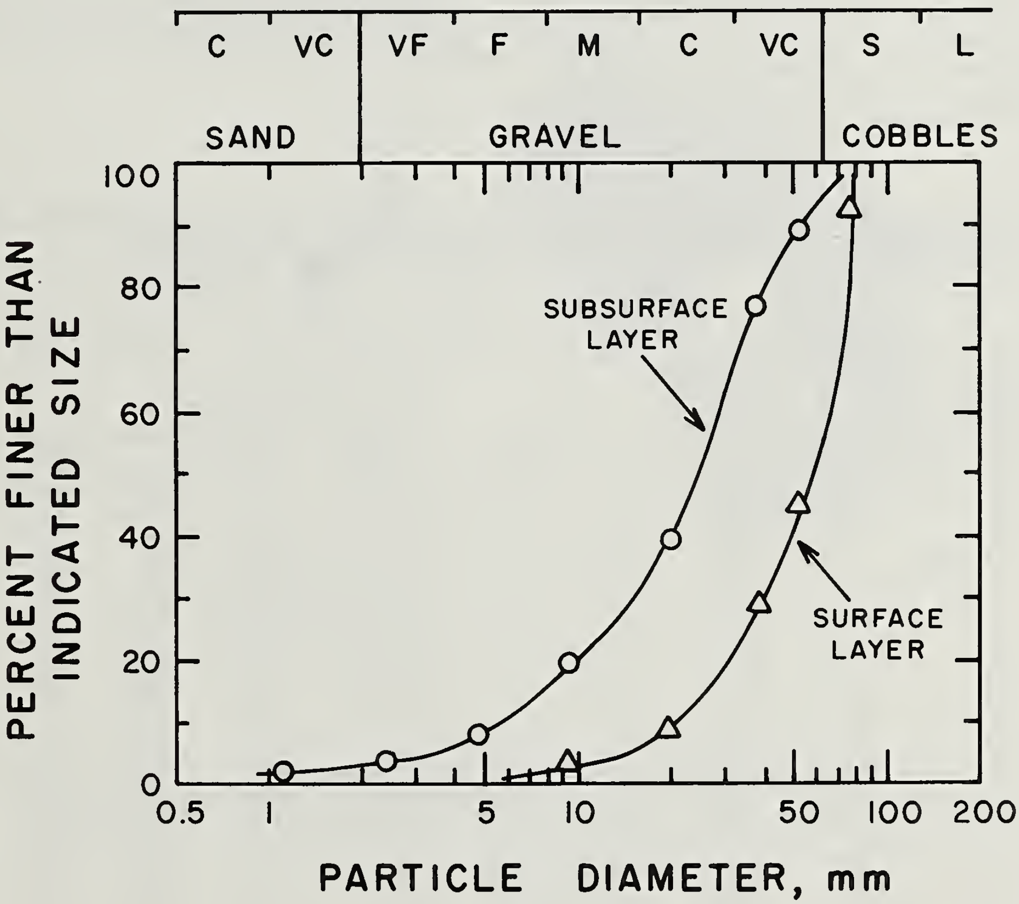

Figure 1.--Particle size distributions of selected stream bed materials in Oak Creek, Oregon Coast Range (after Klingeman and Milhouse 1970).

Both size and shape of individual sediment particles are important ways of expressing the character of material at a particular stream section and facilitating comparisons between sections. An exponential decrease in particle sizes downstream is often characteristic of stream systems although local geologic conditions and the occurrence of tributary streams, which may introduce sediments having a different history or origin, complicate this relationship. Particle shape information may be useful for providing information concerning the mechanics of bed transport and of transport capacity for different types of materials. Several indices for expressing particle shape (based on the relative roundness, flatness or angularity of particles) have been developed for stream sediments (Gregory and Walling 1973).

The role of vegetation in affecting channel characteristics is a complex one (Zimmerman, Goodlett and Comer 1967). Roots may permeate channel banks and provide a binding component which promotes channel stability. In addition, these roots and accompanying stems can further provide mechanical protection from fluvial erosion and alter the roughness characteristics of the channel. Although streamside vegetation characteristics may not be easily quantifiable, a ranking of vegetation characteristics (based on their relative contribution to channel and bank stability) represents one possible way of assessing this component of the channel environment.

When channel-side vegetation dies, there is a high probability that all or part of the above ground portion will enter the channel. This organic debris, such as leaves, needles and twigs, may be quickly processed by aquatic organisms or flushed from the channel during high flows. In contrast large organic debris, such as branches, stems and root wads, may have a residence time within the channel measured in years or decades. This large organic debris may become incorporated into the channel banks and beds, thereby affecting channel morphology and sediment movement (Heede 1976). The total mass of large organic debris in the channel environment can be determined by sampling along predetermined transects (Froehlich 1973). Table 1 illustrates the amount of organic debris loading for several small forest streams in the Pacific Northwest. Mapping the spatial distributions of debris accumulations (fig. 2) may provide additional insights regarding the influence of organic debris upon characteristics of the stream system.

Table 1.--Channel characteristics and quantities of organic debris for several forest streams in the mountains of western Oregon (after Froehlich 1973).

Watershed			Stream Channel				Organic Debris		
Channel Identification	Drainage Area (ha)	Average Side Slope near Stream (%)	Depth (m)	Width (m)	Cross Sectional Area (m^2)	Channel Gradient (%)	Coarse	fine (kg/m)	Total
A	2	71	0.1	0.6	0.1	65	634	18	652
B	4	70	0.2	0.9	0.1	57	667	30	697
C	8	85	0.2	0.9	0.2	60	417	28	445
D	9	85	0.2	0.9	0.2	60	232	50	282
E	10	87	0.2	1.8	0.3	29	309	18	327
F	28	60	0.3	2.3	0.7	7	211	15	226
G	34	90	0.3	3.4	1.0	28	738	30	768
H	36	92	0.4	2.7	1.0	29	360	23	383
I	39	66	0.4	2.7	1.1	15	214	23	237
J	49	73	0.5	2.7	1.4	15	333	23	356
K	57	88	0.5	3.4	1.7	22	24	4	28
L	114	57	0.4	8.5	3.2	10	375	28	403
M	117	62	0.5	5.8	2.9	11	170	22	192
N	163	73	0.8	4.9	3.7	17	423	21	444
O	535	76	0.8	9.1	7.0	10	348	12	360
P	645	38	1.5	4.6	7.0	6	223	18	241
Q	3,043	20	1.7	16.8	27.9	20	83	7	90
Ave.	288	70	0.5	4.2	3.5	27.1	336	23	359

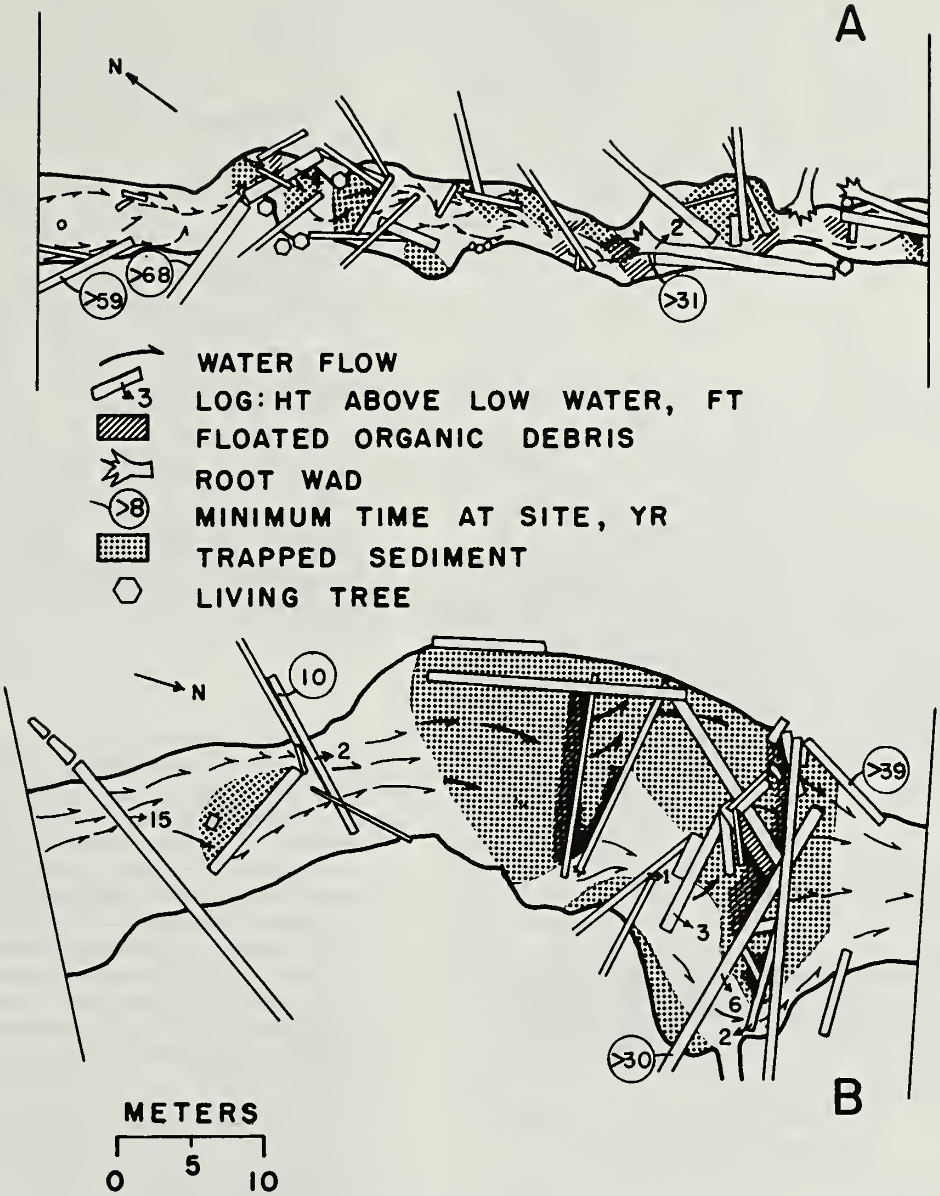

Figure 2.--Maps of large organic debris and other material in 60-m sections of (A) Zog Creek and (B) Mack Creek in the Cascade Mountains of Oregon (after Swanson, Lienkaemper and Sedell 1976, pp. 8, 9).

Transverse Profiles

Transverse profiles (or channel cross-sections) involve width and depth measurements across the stream channel from bank to bank, perpendicular to the direction of stream flow. These measurements characterize channel dimensions and shapes. Because of variability in cross-sectional profiles encountered in small streams, field measurements are often reduced to values which can be compared more easily. For example, the following variables have been determined from the transverse profile shown in figure 3:

Width	= 5.0 m
Depth	= 0.43 m
Cross-sectional area	= 2.15 m^2
Width-depth ratio	= 11.6 m/m
Hydraulic radius (cross-sectional area ÷ wetted perimeter)	= 0.33 m^2/m

Osterkamp and Hedman (1977) have shown that channel width may provide a useful means of estimating average discharge from ungaged basins. The width-depth ratio is a dimensionless parameter which indexes channel shape. Channels with large width-depth ratios generally have relatively unstable banks. Hydraulic radius provides a useful means of quantifying channel characteristics which affect flow dynamics. When used in conjunction with channel slope measurements, an estimate of channel roughness (Barnes 1967) and

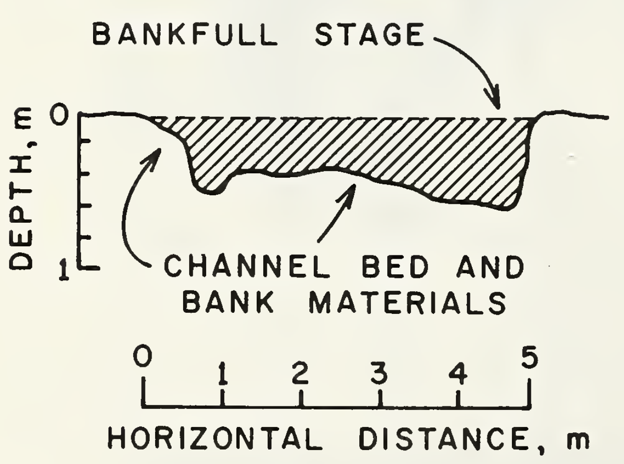

Figure 3.--Transverse profile of Flynn Creek in Oregon's Coast Range. Bankfull stage is usually used as a reference discharge for defining channel dimensions. Although flows which equal or exceed bankfull stage have a relatively low frequency of occurrence, they are important in affecting channel and bed characteristics.

the Manning equation (Avery 1975) it can be used to estimate stream discharges and average velocities. Repeated transverse profiles can indicate the magnitude of channel erosion or deposition associated with certain land use activities (Childers and Jones 1974, Beschta 1977).

For a given stream cross section the mean width (w), depth (d) and velocity (v) of flow have been shown to be power functions of discharge (Q):

$$w = aQ^b \qquad d = cQ^f \qquad v = KQ^m$$

where a, b, c, f, k and m are empirical coefficients (Leopold, Wolman and Miller 1964). The exponents b, f and m describe both the geometry of the channel and the relative resistance to erosion of the bed and banks. Hydraulic geometry relationships have been developed for "at-a-station" as well as for stations in a "downstream direction". From an inventory viewpoint hydraulic geometry relationships can be developed in a downstream direction for a particular flow condition. This could be done during a period when flows were not changing rapidly. In contrast, the "at-a-station" analysis would require the remeasurement of selected channel reaches over a variety of flow conditions and would entail a monitoring program.

Channel Gradients

The longitudinal profile of a stream is a graphical representation of its slope, or gradient (fig. 4). Longitudinal profiles can be determined from topographic maps or field surveys. For headwater streams, this profile is typically concave upward and is controlled by the same variables that influence other aspects of stream behavior such as size of drainage basin, watershed relief, geology, vegetation and climate. Although mathematical curves can be fitted to stream profiles, the constants used in such expression are usually unique to each stream system (Butzer 1976). Stream profiles are seldom smoothly concave. Instead, inflection points in a profile, known as knickpoints, are frequently associated with the effects of past glacial activity, tributary confluences, outcrops of hard rocks or other structural controls.

Within a given stream reach channel slope can vary depending on whether measurements are taken at a pool, a riffle or somewhere between. For gravel bed streams pool-riffle sequences repeat at more or less regular intervals averaging 5 to 7 channel widths in length (Leopold, Wolman and Miller 1964). However, for streams draining wildland watersheds, factors which influence the longitudinal profile can also influence pool-riffle sequences and their spacing may not be as uniform. The length of reach over which a stream's gradient is

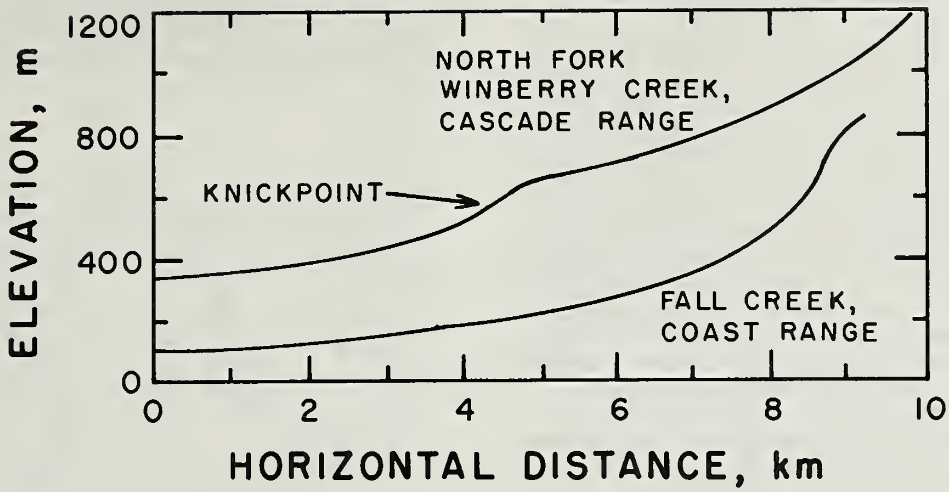

Figure 4.--Longitudinal profile of selected streams in western Oregon.

measured should not be less than twenty times the channel width (Gregory and Walling 1973).

Channel slope or gradient affects the sediment transporting capabilities of wildland streams. This is readily shown in the equation for unit stream power (Yang 1972):

$$U = VS$$

where U = unit stream power, V = velocity of streamflow and S = water surface slope or energy slope. The energy gradient can often be approximated by channel gradient during periods of high streamflow. This equation indexes the rate of energy availability in a stream. A portion of this energy may be utilized for sediment transport and channel erosion. Channel slope is of particular significance because it can be altered by land use activities which alter streamflow patterns or mechanically disturb the channel. For example, the straightening of a channel may increase unit stream power whereas the addition of large stable organic debris may reduce it.

Stream gradients also provide other insights in relation to the effects of mass soil movements. Debris torrents are a relatively common type of mass movement in the steep headwater drainages of Pacific Northwest streams. The length of channel scoured by these events is largely related to the steepness of channel gradients. Debris torrents in Oregon's Coast Range have been found to flow long distances downstream until setting up at channel gradients of 3 to 11% or abrupt changes in channel direction (Swanson and Lienkaemper 1977).

Drainage Densities

The concentration of tributaries and main streams in a drainage basin, as delineated on planimetric maps or aerial photos, can be quantitatively summarized in terms of drainage density. Drainage density is the length of stream channel per unit of watershed area and is derived by dividing the total length of stream channel in a basin by its area. Forested watersheds, underlain by permeable soils and parent materials, will typically have low drainage densities whereas areas of impermeable clays and shales under semi-arid conditions will have relatively high drainage densities. Drainage densities may range from one to over 1,000 for wildland watersheds and are often correlated with streamflow characteristics. Carlston (1963) has shown that the magnitude of the mean annual flood is directly proportional to drainage density whereas base flow levels decrease with increasing drainage densities.

Stream Orders

Each wildland stream is a unique entity with characteristics not duplicated by any other stream. The variability in stream and channel morphology would seem to indicate that stream characteristics are not systematic or predictable, yet the science of fluvial geomorphology has provided ample evidence that streams do have definable spatial patterns. Among the many quantitative tools available for describing the characteristics of stream systems, perhaps none have been more intensively utilized than that of stream orders. A wildland watershed can be subdivided into subwatersheds

of decreasing size with those having the smallest tributaries representing the basic stream units. By classifying these stream units into a hierarchy of stream orders, the organization of stream systems can be quantified. Several ordering systems have been developed (fig. 5) although the system proposed by Strahler (1957) has perhaps been the most widely used. Strahler's method of stream orders classifies a headwater stream that has no tributaries as order 1. Second-order streams are formed by the junction of two first-order stream segments. Similarly, third-order streams are formed by the junction of two second-order streams and so on. The stream segment at the mouth of a watershed always has the highest order. Ordering is useful because it provides a rapid method of quantitatively designating streams or stream segments on any wildland watershed. It can thus form the basis for categorizing stream reaches and comparing inventory characteristics. Map scale can affect the ordering of streams and thus should remain constant over the area of interest. In each case the method of ordering and map scale need to be identified.

Several "laws" have been formulated to express stream order relationships for drainage basins. These are called the *laws of drainage composition* and are stated in Table 2. These laws help formalize and express the fundamental characteristics of stream networks. Stream order is related to the number of streams, channel length and channel gradient by simple geometric relationships; that is, these variables plot as straight line relationships with stream order on semilogarithmic paper (fig. 6).

Table 2.--Laws of drainage composition (after Butzer 1976, p. 186).

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1. *Law of Stream Numbers*. The number of streams of a given order in a drainage basin decreases systematically with increasing stream order.
2. *Law of Stream Lengths*. The average length of streams of a given order in a drainage basin increases systematically with increasing stream order.
3. *Law of Basin Areas*. The average drainage-basin area of streams of a given order increases systematically with increasing stream order.
4. *Law of Channel Maintenance*. The average length of stream channels of a given order increases systematically with increasing average drainage-basin area of a given order.
5. *Law of Stream Gradients*. The average gradient of streams of a given order decreases systematically with increasing stream order.

However, some stream systems may not conform to the laws of stream numbers or stream gradients because of exceptional structural controls or underdeveloped stream systems (Heede 1970).

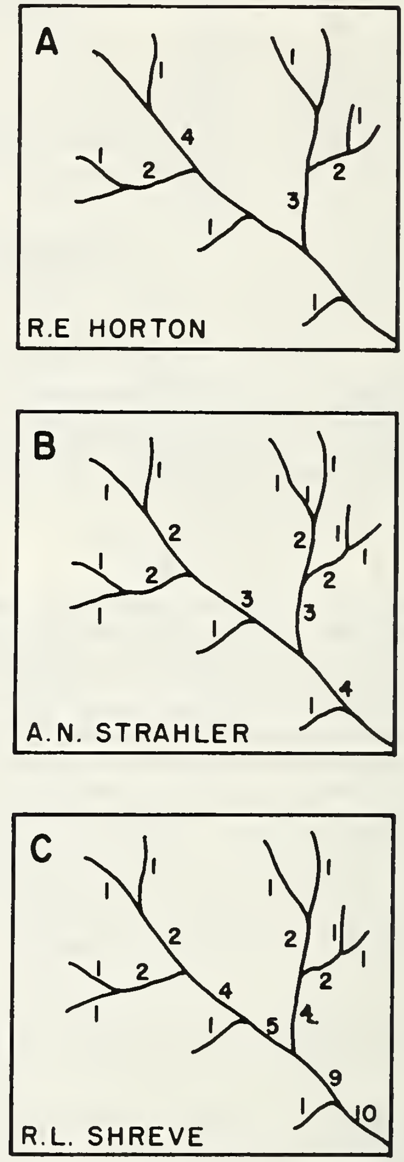

Figure 5.--Methods of stream and segment ordering (after Gregory and Walling 1973, p. 43).

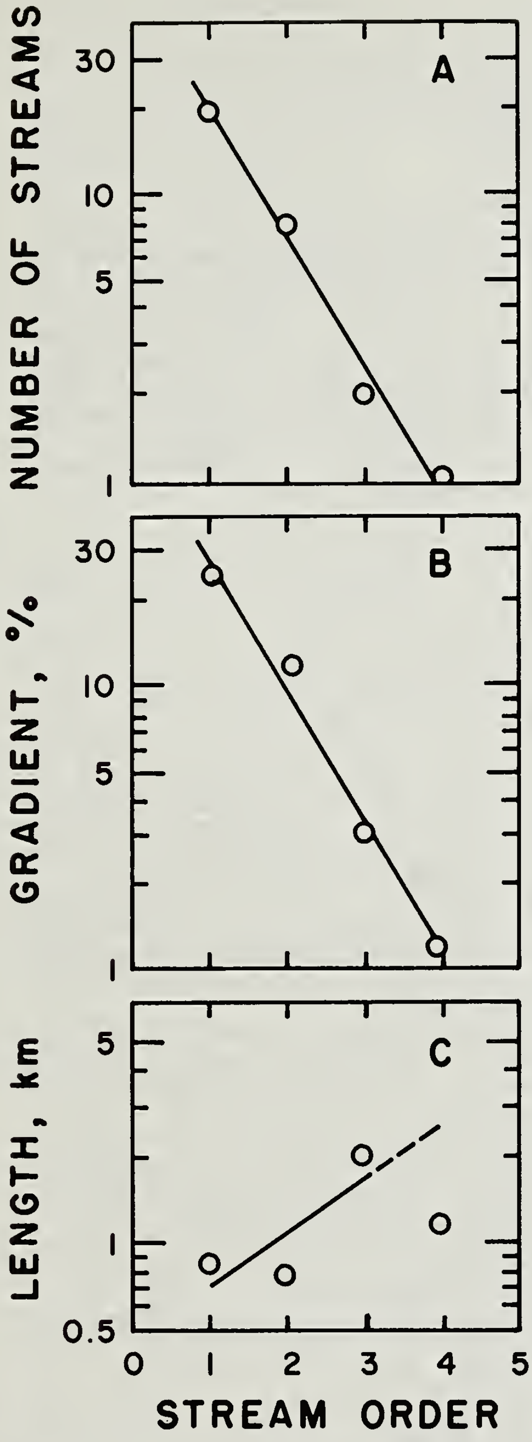

Figure 6.--(A) Number of streams, (B) average gradients and (C) average lengths in relation to Strahler's stream orders for the Mill Creek drainage in Oregon's Coast Range (Map scale = 1:62,500).

STREAM AND CHANNEL INVENTORIES

Herrington and Dunham (1967) and Platts (1976) have found that stream channel measurements (including depths, widths, channel substrate composition, percent pools and riffles, and others) can provide the basis for describing environmental conditions which are correlated with instream fish habitat and populations. Another type of inventory, which is currently being used by the USDA Forest Service in the northern Rocky Mountains, is the "Stream Reach Inventory and Channel Stability Evaluation" (Pfankuch 1975). This inventory and evaluation entails an in-the-field assessment of stability of upper and lower channel banks and the channel bottom. Measurements and qualitative judgements for 15 items are used to index channel stability. The numerical and qualitative classifications which result from this method can be used to indicate the relative stability of various channels and their sensitivity to disturbance.

In California, Oregon and Washington, stream classifications have recently been used as a basis for delineating acceptable and unacceptable forestry practices (Oregon Department of Forestry 1975, Washington Department of Naturaal Resources 1975, and California State Board of Forestry 1976). These stream classifications, however, have been based largely on the relative importance of various beneficial uses of the waters. For instance, Oregon's Forest Practice Rules (Oregon Department of Forestry 1975, p. 3) define a Class I stream as "... waters which are valuable for domestic use, are important for angling or other recreation and/or used by significant numbers of fish for spawning, rearing or migration routes." Class II streams are defined as "... any headwater streams or minor drainages that generally have limited or no direct value for angling or other recreation. They are used by only a few, if any, fish for spawning or rearing. Their principal value lies on their influence on water quality or quantity downstream in Class I waters." All flowing waters in forested areas of Oregon are classified as either Class I or Class II streams. Thus, biological, social and political judgements have often been more important in developing stream classifications than physical stream or channel characteristics. Although these legislative classifications further illustrate the importance of wildland streams, they have, to a certain degree, preempted the need for quantifying or evaluating the physical characteristics of streams and stream systems.

SUMMARY AND CONCLUSIONS

There are numerous characteristics of small streams and channels that are amenable to an inventory approach. The ultimate choice as to which characteristic to measure lies with the land manager and will be influenced by a variety of factors. However, a frequently ignored component to any inventory program is that the objectives and ultimate use of the inventory data need to be thoroughly identified before data are collected.

The natural variability in climate, geology, physiography and vegetation types found on undisturbed wildland watersheds all influence the characteristics of a stream and its associated channel system. This complexity of watershed characteristics is in turn illustrated by the spatial and temporal variability of wildland streams. In spite of the complexities and problems associated with inventorying small streams such information is becoming increasingly necessary.

A "standard" stream reach inventory does not exist for wildland watersheds. Instead, inventories are often tailored to the particular objectives and information needs. Two general types of inventories can be identified. The first involves a generally detailed quantification of a selected stream or location and may be used for intensive project planning or where stream values are particularly high, and detailed information is desired. The second type of inventory requires measurements at several locations along a given stream or along several streams. This type of survey can provide base-line information to be used for general planning purposes or for evaluating relationships between different categories of streams.

The preceding discussion of selected measurable attributes of wildland streams is by no means complete. They have been selected, however, to illustrate a range in the types of inventory measurements that may be used to quantify a channel network. The end product of most stream inventories is a classification of stream channels into discrete categories. These categories provide land managers with information about a stream or stream system. Results of such inventories will be of most value to land managers who have definite water management goals and can relate these goals to the impacts of other resource uses and activities.

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A Short Survey of the Worldwide Forest Inventory Methodology[1]

Tiberius Cunia[2]

INTRODUCTION

It is almost an impossible task to make a complete survey of the methodology of forest inventory as presently used around the world. Although the basic features of this methodology can all be traced back to standard sampling techniques, and almost any existing standard sampling concept is being used in forest inventory, the human mind is so inventive that uncountable specific methods have been devised to take the timber inventory of a forest land. Many of these methods have never been described in printed form. Or if described, they have appeared in a variety of languages and journals. Because the worldwide literature in this subject is very large and because one must know many languages to have access to it, it seems an insurmountable task to analyze, sort out, and summarize the main features of the worldwide forest inventory methodology.

Consequently, what I shall try to do here is to offer a rather general look at some of the most important inventory methods as used in some of the countries around the world. Most of what I will say now is derived from several papers and textbooks that came across my desk in a more or less random fashion. And because this is the third time in less than four years to talk on a similar subject, I will draw heavily from, and possibly update, the material presented in two previous papers, Cunia (1974, 1975).

To facilitate my expository talk I shall discuss separately several classes of sampling methods as applied to forest inventory. I shall not discuss the mensurational or data processing aspects of these methods. Rather, I shall concentrate my talk on the statistical features of the various sampling designs.

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STAND BASED FOREST INVENTORY TECHNIQUES

With the possible exception of the complete tree enumeration, the stand based inventory method appears to be the oldest. Because most of the European forest management is based on the stand concept, these methods were specifically designed in the past to be used in conjunction with the preparation of the management working plans. The forest area is first subdivided into homogeneous stands of roughly the same age, species composition and site quality. Then, the stand is visited in the field, its general conditions or main parameters ocularly estimated and recorded. Finally, the timber volume within the stand is read from previously constructed yield tables according to the specific stand parameters and general description.

Due to the subjective character of this method, no statistical statement can generally be made about the precision of the volume estimates; and, thus, the methodology seems hardly fit to satisfy the needs of the modern forest management as we perceive them today. Nevertheless, according to Loetch, Zöhrer and Haller (1973) and Nyyssönen (1976) this inventory method is still being used in one form or another, in several countries in Central and Eastern Europe. Improvements to the basic method as described above have been brought in these countries, and they consist mostly of (1) the replacement of the field description of the stand by aerial photo-interpretation, (2) use of sampling to replace the ocular estimation of the stand parameters, or (3) the removal of the inherent bias of the method through a statistical selection of sample stands that are 100 percent measured or statistically subsampled.

It may be interesting to note that in a somewhat different form, this inventory method is also presently applied in the United States and Canada whenever the unit in the forest management system is the individual forest stand. This is the case, for example, in the southeastern United States where the volume and growth of the pine plantations is often estimated by yield tables or growth and yield functions. According to Avery (1974), the detailed stand data cannot be obtained efficiently by the usual inventory procedures because the required sample size would be prohibitively

high. Then, growth and volume estimates can be more easily derived from yield and projection equations that are based on plantation age, site index and original tree spacing. Once such yield functions have been constructed and tested for accuracy, the field work often becomes extremely limited if not completely unnecessary.

Another American system of stand based inventory is that of Weyerhaeuser Company. As described by Depta (1974), the basic characteristics of some 100,000 individual forest stands are stored in a computer. The stand boundaries are normally delineated through aerial photo-interpretation and the stand shaped as an irregular polygon is stored in the computer as the set of coordinates of the polygon vertices. The timber within the stand boundaries is described by a few parameters such as species, age class, basal area, and number of trees per acre, average and range of tree diameters, stand height, etc. These parameters are estimated through field cruises or aerial photo-interpretation and they are also stored in the computer. Through the use of previously defined mathematical models, the stand volumes, averages or totals, stock and stand tables, etc. are generated by the computer. Finally, the calculation of the inventory growth is obtained through an update of the stand description and re-run of the mathematical model.

Finally, the inventory method used by Province of Ontario in Canada falls also in this category. According to Caesar (1975), forest type maps are prepared based on photo-interpretation and a limited number of ground plots. The volumes are then estimated through normal yield tables using the stand description (basal area, age, species, site) as determined above.

METHODS BASED ON COMPLETE TREE ENUMERATION

This inventory method requires that every tree in the population of interest be visited in the field and measured. Sometimes, the tree volumes are all individually measured. This may be the case, for example, with small experimental forest areas where it is important to measure the tree volume and growth as accurately as possible. Most of the time, however, the trees are only measured for characteristics such as diameter at breast height, merchantable stem length, etc., or described qualitatively for their species, visible defects, percent of sound wood, grades of potential logs, etc. Then, to go from this tree description to tree volume, the variable of interest, one may use either (1) techniques based on volume measurement of subjectively selected sample trees of average characteristics, (2) previously constructed volume tables, or (3) volumes of randomly selected sample trees, or trees selected by the 3P Sampling procedure.

Let us consider first the methods using the volumes of sample trees of average basal area or volume. Described in the old American mensuration text by Graves (1906), these methods are practically unknown today in the United States. However, they are still in some limited use in Central Europe and, thus, their description is still included in modern European mensurational textbooks such as those of Prodan (1965) and Giurgiu (1969). For a brief summary discussion of these methods, the American reader may refer to Cunia (1974). In short, the typical method requires that all merchantable trees in a given stand be measured for their diameters and some representative trees be cut down and measured for their diameter and volume. The total volume of the stand is then estimated by appropriate formulae, the building block of these formulae being of the form

$$V = B(v/b)$$

where V and B are the total volume and basal area respectively of the stand and v and b are the volume and basal area respectively of the sample trees.

Basically, the various methods differ by the procedure by which the sample trees are selected. In addition, recent improvements of the method have replaced the 100 percent tree tally by estimates based on sampling. One can use the ordinary sampling procedures based on sample plots or relascope sample points, or one can use newer techniques based on average distance between trees, average distance from a randomly selected point in the forest to the n-th closest tree or networks of non-overlapping triangles with trees as corner points.

Although from a statistical point of view one cannot calculate the accuracy of the estimates derived by this method, some authors have recently suggested formulae to approximate this accuracy. And surprisingly enough, empirical studies comparing estimates with the corresponding harvested volumes, some of these studies made as recently as 1968, showed according to Giurgiu (1969) a very close agreement.

Let us consider now the complete enumeration methods that make use of some sort of previously constructed volume tables. These methods are currently applied in many countries in the world, including the United States, and they are used to estimate the volume of the trees to be removed in thinning of stands or timber sales operations. In short, the trees to be sold are marked in the field and usually

measured for their diameter; but depending on their value, the trees may also be analyzed with respect to the size and quality of logs into which the tree may be processed. The volume or sometimes value of the trees is then determined either from accumulation of log volumes (as calculated from appropriate log rules) or with the help of previously constructed, theoretical or empirical tree volume tables. Except for improvements in the methodology of volume table construction, these inventory methods remain essentially the same as devised a long time ago.

Let us consider finally the timber sales inventory using the 3P Sampling procedure. Introduced some 15 years ago by Grosenbaugh (1963), the 3P Sampling concept has found wide acceptance in America but to my knowledge, it is not applied anywhere else. This is probably due to the fact that although the procedure is relatively easy to learn how to apply, it is also relatively difficult to understand why it works.

The timber sales inventory method using 3P Sampling can be described as follows. Each tree to be sold is visited in the field in some arbitrary order and the timber cruiser predicts (or estimates) to the best of his subjective judgement its value (or volume) by ocularly analyzing the tree characteristics. To decide whether the specific tree is to be included in the sample, the cruiser uses a mechanical procedure which insures that the probability of the tree selection (in the sample) is proportional to the predicted tree value. If the tree is not a sample tree, then the cruiser moves to the next tree and repeats the whole procedure. But if the tree happens to be selected, the value (or volume) of the tree is measured as accurately as possible. Finally, the predicted values of the entire set of trees and the actual values of the sample trees are combined in a suitable way so as to yield the total sale value (or volume).

In the usual version of this inventory method, several diameter measurements outside bark are taken along the tree stem with an optical dendrometer of high precision, the bark thickness is measured at breast height and the tree quality and external defects of various tree sections are finally assessed. All these measurements are then translated into a tree value (or volume), usually but not necessarily with the help of a computer. Because the dendrometer measurements cannot say what is inside the tree, a newer version suggested by Johnson and Hartman (1972) requires that all sample trees be actually cut down into merchantable logs in the best possible way and that the tree value established through the measurement of the values of its logs.

INVENTORY BY SAMPLING METHODS FOR ONE OCCASION

Among the basic sampling methods the systematic sampling is the most intuitively appealing. For this reason it has been applied to forest inventory for a very long time, way before statisticians started to study its properties. According to Nyyssönen (1976), strip sampling, which is a form of systematic sampling was first introduced in the Scandinavian countries by Ström as far back as 1830 and the method was in common use in these countries all through the 19th century.

The classical systematic sampling as applied to forest inventory has two main forms, the strip sampling and the plot sampling. In the first form the sample units consist of equidistant parallel strips of specified width running over an entire forest area. The sample units for the plot sampling, on the other hand, are equidistant sample plots, the location of which is ordinarily determined by a transparent dot grid randomly layed over the forest map. The merchantable trees falling within these strips or plots are all measured for their species (or species groups) and diameter at breast height and some of the trees for additional characteristics such as tree height, age, past growth, etc. Finally, the tree volumes are determined from previously constructed volume tables, and forest statistics such as averages per unit area, total volume, or stock and stand tables computed.

The main advantage of systematic sampling is the simplicity with which it can be applied in the field. In addition, it is generally more efficient than the simple random sampling, its most obvious alternative; the sample units are much more evenly spread over the forest area. The main disadvantage, however, is that one cannot derive statistically acceptable expressions for the precision of estimates. Empirical studies made in several countries have shown that treating the systematic sampling as random, results in an overestimation of the standard error. Some of the better, but more complex procedures for the calculation of the precision can be found in the Husch, Miller and Beers (1972) textbook. Finally, a new procedure using the theory of regionalized variables is being promoted in France; according to Bouchon (1976) this procedure yields, for the same sample data, confidence intervals that, on the average, are about 30 percent narrower than the corresponding intervals calculated by the simple random sampling formulae.

The basic systematic sampling design as

described above is still being applied all over the world. And this design is probably the best to use with small forest areas that are relatively expensive to stratify and separate estimates by stratum are not required. But as foresters became increasingly acquainted with new statistical concepts and methodology, and as the management problems became increasingly more complex, the basic sampling designed above changed with time to the point where the systematic lay-out of the sample units has been completely eliminated.

One simple way to improve the estimates from a systematic sample is to post-stratify the forest area into more or less homogeneous types. Then, the estimates for each forest type are calculated separately from the data of the plots that happen to fall within that type and the estimates from all types are suitably combined to derive estimates for the overall forest area. The forest borders are ordinarily delineated from aerial photo-interpretation and the procedure had the added advantage of yielding estimates separately for stands as needed. This procedure is probably as efficient as the corresponding pre-stratification with proportional allocation. But as soon as foresters became aware of the big gains in efficiency that may be obtained through stratification, they started using the concept of stratification with optimum allocation. The procedure of pre-stratified sampling with proportional or optimum allocation, where the strata are delineated by aerial photo-interpretation and where the sampling within strata is done systematically, is probably one of the most common inventory procedures in use today around the world.

Sometimes the inventory must be taken over large forest areas covering entire regions or countries. The inventory objectives may not require estimates by individual stands and the stratification of these areas into homogeneous forest types may become extremely expensive and time consuming. Then, the advantages of stratified sampling with optimum allocation can be preserved to a large extent by using the following double sampling procedure. First, a very large number of points are randomly or systematically located on aerial photographs of the forest area of interest and through photo-interpretation, each point is classified as belonging to one of previously defined strata. The proportion of points falling within a given stratum provides an estimate of its true proportion. Then, a stratified sub-sample (with optimum allocation) of photo-points is selected and for each photo-point in this subsample a field plot is established. Finally, through volume tables the plot volumes are calculated and through statistical theory the volumes by strata or for the overall forest are determined. Double sampling for stratification is being currently used in several countries for the inventory of large forest areas. For example, it is the procedure used in the National Forest Inventories of France and Spain, the provincial inventory of New Brunswick in Canada, and the inventory systems devised by the Northeastern Forest Experiment Station and BLM in the United States.

Changes in the basic method occurred also in the definition of the sample units. We may have a strip sample of fixed width type or a line sample of variable width. The simple plot of fixed constant area may be replaced by a relascope point sample or a circular plot of the variable-radius type. The single plot may also be replaced by clusters of plots. For example the sample unit of the national forest inventory in France is defined as a cluster of two or three plots, with each plot consisting of three concentrical circular areas of various radiae (6, 9, and 12 or 15 meters); the three sizes are used to measure the small, middle size, and large trees respectively. The sample unit of the CFC systems used in Canada by Canadian International Paper Company is defined as a set of one primary and two satellite plots of fixed area. The Northeastern Forest Experiment Station and the Bureau of Land Management use clusters of ten variable-radius plots. And as reported in an earlier paper, Cunia (1974), the national forest inventories of Sweden, Finland, and Austria use sets of sample plots or relascope sample points located on the sides and/or vertices of rectangular forest areas.

Lately, the forest inventory method has been greatly improved by the addition of Grosenbaugh's 3P Sampling concept. The new inventory systems have been described, among others, in papers by Steber and Space (1972), Space (1974), Van Hooser (1974), Cunia (1975, 1976), and Space and Turman (1976). The new, two-stage type designs can be briefly described as follows.

The first stage consists of a set of fixed area or variable-radius sample plots selected by the systematic, random or stratified sampling methods. The trees of these sample plots, hereby called the first stage trees, are measured in the usual way and classified as needed into groups by size, species, quality class, possible utilization, etc. A subsample of the first stage trees is now selected so that each tree has a probability proportional to its size of being selected. These are the second stage trees and they are measured with an optical dendrometer for their visible defects and diameters at various points along their stem. Finally, the mensurational

data of the first stage trees, together with the dendrometry data of the second stage sample trees are fed into a computer where the latest version of the STX computer program converts the field data into volume estimates for the given forest area within any desired breakdown by size, species, quality class, product type, etc.

Forest inventory with 3P Sampling is a very powerful and efficient technique. It eliminates the need for volume tables as we know them, and, thus, corrects for most of their drawbacks. It also eliminates the need for writing and debugging specific computer programs. Provided that one follows a general and flexible set of field procedures, STX program is fully debugged, operational and can be obtained free of charge from the U. S. Forest Service. The only disadvantage may be the fact that the concept of 3P Sampling is hard to grasp intuitively and non-statisticians must make a major effort to learn the system and its capabilities.

In the last decade or so attempts have been made to make a more extensive use of small and large scale aerial photography. Although the present use of aerial photography is mostly in the forest area stratification, new inventory systems have evolved that make use of multi-stage and double sampling with regression techniques. As these systems are less known perhaps, let us summarize below their basic features. For more details the reader may refer to papers by Bonnor and Aldred (1974) and Langley (1976) among others.

Large scale photographs of randomly or systematically selected sample plots can be used as the first phase of a double sampling with regression design. The volume of these plots is determined through photogrammetric measurements of their trees or by subjective photo-interpretation of their characteristics. A small random subsample of these plots is then selected and through ground measurements their actual volume is determined as accurately as possible. Finally, the two sets of data, the photo and ground plot volumes are suitably combined through regression techniques and estimates of the forest area volumes computed.

Because it is almost as easy to take large scale photographs of single plots as it is to take photographs of long and narrow strips, one may also use the following two stage, double sampling design. The first phase may be defined as a two stage cluster design. The primary units are narrow strips of forest land of various lengths and the secondary units consist of rectangular subdivisions of plot size of these strips. Large scale photographs are then taken of randomly selected strips and the trees from random samples of plots randomly selected from the sample strips are measured photogrammetrically for their size, usually height and crown width. The second phase consists of randomly selected trees measured for both, photogrammetric measurements of height and crown width and ground measurement of volume. Using the second phase trees, tables of tree volume on height and crown width are then constructed and these tables are finally applied to the trees of the first phase to determine the volume of the forest area.

For inventories of large forest areas, the two-stage design above can be improved by using an additional stage. For example, from small scale photography of the area, more or less homogeneous stands are identified, delineated and grouped by strata. A stratified random selection of stands (using equal probability or probability proportional to size) constitute the first stage sample. The sample units so selected in this first stage are then subsampled either by the two stage design described above or any other appropriate multi-stage or double sampling design.

SAMPLING METHODS FOR SUCCESSIVE INVENTORIES

Modern management requires a continuous flow of updated information about forest resources. To continuously monitor the conditions of a given forest area, one may take its inventory on a periodic basis using any of the statistical designs described in the previous section. This is what usually happens, and it is not uncommon to see in most countries inventories updated periodically (ordinarily between 5 and 20 years) by some of the sampling methods described in the previous sections.

One common feature of most of these periodic inventories is that, over the various occasions, they are taken independently of each other. While the precision of current estimates remains acceptable over the successive inventories, the precision of the estimates of the changes in current values from one to the next measurement is, however, very low. The reason for this phenomenon can be easily demonstrated by statisticians; the variance of the difference between two statistically independent estimates is equal to the sum of their variances.

What seemed obvious to statisticians became intuitively obvious to some American foresters some forty years ago. They felt that if they were to obtain reliable and efficient estimates of the forest growth and its main components (growth on living trees, ingrowth and mortality) they had to make use of permanent

sample plots. And this is how Continuous Forest Inventory or CFI came into being. A set of systematically selected and permanently established on the ground plots that could be measured at any desired point in time provides a basic inventory system which preserved the same precision for current estimates (for equal number of plots) but increased tremendously the precision of the growth components estimates.

The classical CFI system as used in our as well as other countries makes use of systematically selected circular sample plots of fixed area. Other continuous forest inventory systems make use of variable-radius sample plots. In addition, the single plot of the classical CFI may be replaced by a cluster of plots or the systematic by the stratified, cluster, or double sampling designs. We have already stated that the Canadian International Paper Company uses clusters of three fixed radius plots and that the Northeastern Forest Experiment Station uses clusters of ten variable-radius sample plots selected within a more complex double sampling for stratification design.

Judging by the success of their application, two statistical concepts are at the basis of two major improvements in the basic CFI systems. Some twenty years ago it became obvious that the efficiency of the CFI system can be greatly improved if at remeasurement time, only a part of the permanent plots is remeasured with the remaining part replaced by a new set of sample plots; this is the basic concept of sampling with partial replacement or SPR. And then, some five years ago, the 3P Sampling concept and the list sampling with probability proportional to size were applied to the remeasurement of the previously established CFI plots. The SPR has been applied in Eastern Canada, Northeastern United States, and Australia, and at least tried if not currently applied in other countries such as for example in Finland or Romania. And according to Bouchon (1976), the French foresters think about using SPR at the remeasurement time of their national forest inventory. On the other hand, 3P Sampling within this context has only been applied in the southern United States.

No studies have been made yet to see whether 3P Sampling is generally more efficient than SPR to apply in forest inventory on successive occasions or vice-versa. Probably one method is more efficient with some management objectives and forest conditions and not so efficient with others. Also no attempts have been made to combine the two concepts and develop a system that would increase their effectiveness.

CONCLUDING REMARKS

We have made a survey of the main inventory techniques as presently used around the world. One should note the great variety of sampling concepts used and the great variety of the resulting inventory systems. Undoubtedly, there are many other systems that have not been mentioned here; most of these designs are either unknown to me, or if known, including them all in a short paper was not possible.

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The Techniques and Principles of Soil Surveys on Forest Lands[1]

E.C. Steinbrenner[2]

Techniques of mapping soils on forest lands as developed and utilized by the Weyerhaeuser Company on its mountainous lands in the West and coastal plains in the South is described briefly. Types of interpretive information and its use in forest land management are discussed.

The mapping of soils on Weyerhaeuser lands has been a continuous activity since 1962. Since then, over two million hectares have been surveyed in the West, and another 400,000 hectares mapped in the South. Represented are a wide range of physiographic conditions, and a broad variety of timber types.

Our soil surveys have included forests of Douglas-fir in the Washington and Oregon Cascades, western hemlock along the Pacific Coast, and ponderosa pine with its associated species in southern Oregon. Elsewhere we have mapped the soils in loblolly pine forests along the lower Coastal Plain of North Carolina, in the Ouachita Mountains of Arkansas and Oklahoma, and in northern Alabama and Mississippi.

The program uses the soil series concept developed by the Soil Conservation Service. At the same time, strong emphasis is placed on the interpretation of morphological characteristics that hold biological and engineering significance for forest land management.

Soils are mapped to a relatively high intensity in minimum units of 2 hectares for contrasting conditions, and of 8 hectares for units that may change only in slope class. The procedure depends heavily on the stereo-interpretation of aerial photographs, although the precise techniques vary somewhat between the mountainous terrain of the West and the gentler topography of the South. Throughout, landforms are mapped in conjunction with soils since in steep country they have as much, or even greater, significance than the soils themselves; this significance of landforms is obviously less, however, in relatively level areas.

My discussion will deal with the techniques of soils mapping, and the development and application of soils information to forest land management.

MAPPING TECHNIQUES

The first step in the mapping process is acquisition of pertinent data on climate, soils, and geology for the survey area. In addition, aerial photographs with full stereo coverage must be obtained and prepared for mapping.

Next comes development of a mapping legend, through field reconnaissance of the area to be surveyed.

It lists each soil series and its associated landforms, within each geologic unit, by name and symbol; although not complete, the legend should contain a high proportion of the soils in the area. Subsequently, in the course of detailed mapping, additional soils may be added to the legend as they are encountered. But with a preliminary soil-landform legend in hand the surveyor is ready to begin mapping in the field.

Field mapping techniques for mountainous areas and the relatively level southern coastal plains are quite different, and will be discussed separately. In the former an initial step is to draw a logical survey boundary that encompasses all the land to be surveyed. Only rarely will there be a broad

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pattern of contiguous private ownership. In the private sector an individual land owner may own only 60 to 80 percent of the land included within the boundary. Nonetheless, a substantial area must be surveyed since soil-landforms must be mapped as a continuum. It would be more difficult, and more costly, to stop mapping and exclude non-ownership than to include it in the mapping process.

Field mapping in the mountains is accomplished by driving all passable roads; noting soil and landform breaks where they occur; and taking slope readings and short soil descriptions at 0.8 kilometer intervals. The latter is facilitated by road cuts which afford the surveyor view of soil color, rocks, and rock volumes in exposed profiles; along older roads it may be necessary to clean away the slough, or vegetation.

Usually a survey is begun at the highest elevations, and progresses by following soil materials from their point of greatest erosion to their place of deposition. On completion of a township the surveyor returns to his office where, by viewing the photos in stereo, he is able to delineate landforms and assign soil-landform symbols from the legend prepared earlier. After checking the units and edge-matching all detail within and between townships, a portion of the survey is then ready for the cartographic process. About 40 percent of the time required to map a township is spent in the field, and 60 percent in photo interpretation -- although this may vary with the extent of the road system on the area, and the complexity of the geologic formations.

On the Southern coastal plain the procedure differs from that in the mountains in that soil boundaries must be established on the ground. Soil differentiation through photo-interpretation is precluded since, for the most part, parent materials are marine sediments that have been differentially deposited with no predictable pattern; in addition, there is a notable lack of topography. So -- since the soils are mapped by examination -- there is no need to map more than the ownership of interest regardless of its dispersal. Some of the more obvious landform changes (such as sand ridges and drainage patterns) may be pre-mapped in the office, but the soils must still be checked in the field. Other features are so generalized they may include several soils. Then, since there are few road cuts on these flat areas, the surveyor must refer to ditch banks on the periphery of the survey to establish the soil continuum, and check for changes by probing in the interior of the unit. Under these conditions aerial photos may be carried in the field and soil boundaries delineated as they are found. Field mapping under these conditions takes 3 to 4 times as long as photo interpretation in mountainous terrain. About 80 percent of the time is spent in the field and 20 percent in the office checking and matching photos.

One further procedure is common to all soil surveys when work on a unit with similar parent materials is completed. Modal soils are selected for sampling and description from the legend and range of characteristics allowed in the course of mapping. Physical and chemical analyses are performed for each horizon to characterize the series.

CARTOGRAPHIC PROCESS

Sufficient USGS quadrangles are obtained to cover the entire survey area, and spliced together to form township units. Then each map is enlarged to the scale of the aerial photos; for mountainous terrain this is usually 1:12,000. In those portions of the country where properties are defined by meets and bounds, the quadrangles are increased in size to represent 40,000 feet on a side, and keyed to the State plane grid; then each is referenced to the grid numbers. These are the base maps to which soil-landform detail will be added.

Detail inked on the aerial photos is transferred to the base using a stereo plotter that adjusts photo scale to map scale. Where there is little topographic relief non-stereo plotters may be satisfactory. Subsequently, each map is checked for accuracy, and the soil-landform details edge-matched to adjoining townships.

As a preliminary to computing acreages a paper print is obtained of the mylar base map, the ownership pattern and major intervals of elevation added to it, and the whole overlaid with the soil-landform map. Then acreages are computed for each mapping unit by ownership, section, and average elevation although this latter classification is disregarded on the southern coastal plains. Either an optical planimeter or any of several electronic devices may be used to establish these acreages.

Finally, the soil-landform overlay is inked, details such as a scale and titlings are added to the base, and then both base map and soil-landform overlay are ready for printing. Reproduction is usually at a scale of 1:24,000 or 1:31,680 for inclusion in a final report, although bases and overlays may

also be reproduced at photo scale on a sepia master as an aid to future copying.

MANUSCRIPT PREPARATION

Data derived by acre counting are processed through a computer and each soil-landform unit listed by location and ownership with an aggregate total for all like units in the survey. From this report a master legend is prepared which assigns interpretations to all soil-landform mapping units. These vary with region, and are keyed to which soil-landform characteristics are important for management. For example, soil drainage is the most important soil characteristic on the lower coastal plains in North Carolina but has little significance in the mountainous West. On the other hand, interpretations such as productivity and trafficability are appropriate to all areas.

Eventually, a machine-generated report lists soil-landform data matched to interpretations from the master legend for the entire survey area. These data are then re-sorted in reciprocal fashion to provide a report showing all mapping units, locations and acreages by ownership for each interpretation class. Only interpretations with research backing that are important to forest operations are included.

Forest soil survey reports should be prepared with the user in mind. The biggest problem will be getting the information into practice and so the data should be presented simply and practically, yet without sacrifice of technical correctness. We have found it helpful for each report to include three sections. The first presents background information on geology, geomorphology, climate, soil associations and summaries of the interpretive information. The second includes descriptions of each soil-landform mapping unit; sufficient information for the user to be able to recognize the different soils in the field; a statement of each soil's extent and location; the inclusions that may be found with each; the soils with which they may be associated; and interpretations for each soil's management. The third, and largest, section of each report contains the soil-landform maps with a legend that identifies each soil series and its associated landforms and modifications with the mapping symbols.

USES OF FOREST SOIL SURVEYS

Before discussing the uses of forest soil surveys it may be useful to summarize the various materials that are included in the survey package produced by the Weyerhaeuser program. Sufficient copies of the report are printed to satisfy anticipated needs, but in addition, map separates are produced. These can be conveniently marked up to show all mapping units with a common interpretation. Base maps and soil-landform overlays at photo scale can be used in conjunction with timber inventory data at the same scale. Computer listings of the survey data and individual interpretations are made available to all potential users. And, finally, assistance is provided users in the use and interpretation of these materials by the survey staff.

The uses to which a soil survey is put depend primarily on the interpretations that are provided, and the administrative level of the informational need. For instance, the forester, engineer, or logger may be interested in some characteristic of a single mapping unit. But the regional planner may be interested in much broader categories of interpretation that impact future activities. And administrators at still higher levels may use a summary from all surveys in support of long-range management decisions.

At virtually all levels of forest land management the <u>productivity</u> ratings of the mapped soils are of particular significance. Forest practices should be designed to maintain or enhance this productivity, but this in turn dictates the economics of land acquisition and forest practices.

<u>Trafficability</u> of the soil is another interpretation of broad significance since its application can avert excessive and often irreparable damage to the soil. The interpretation impacts the types of equipment that may be used, and also imposes seasonal limitations on woods operations.

In the West, <u>windthrow</u> is of economic consequence along cutlines and in thinning operations and is related to soils and landforms as well as climatic conditions. Application of soil-landform interpretations can minimize the losses.

In virtually all areas it is valuable to have some prediction of the <u>engineering characteristics</u> of soils and parent rocks prior to road construction, and for subsequence maintenance; anticipated <u>slope stability</u> is also important. Even though a forest property is well-roaded before soils data are gathered there will be a continuing need to

improve, repair and modify existing road systems, and knowledge of rock sources can be invaluable.

Slope and elevation classes may have direct and important applications to forest land management, but derivative from them is a topographic summary and a thinnability report. In the topographic summary mapping units are listed in five slope classes for each 500-foot elevation class, for each productivity class. This information provides an insight to distribution of each category of land, thereby enabling more realistic projections of equipment needs and schedules for various forest practices. In conjunction with operating maps the same information can be used to schedule future regeneration needs. The thinnability report lists acres by gentle or moderate slope classes; by their smooth or broken surfaces; and by their soil limitations, for each productivity class. From this report, the user can determine which portion of an area is amenable to intensive forestry practice; which areas should permit the highest return on the investment; which areas may present difficulties to equipment; and which soils may be operable only during certain seasons. This information is especially important at the onset of intensive forest management since it permits development of priorities.

In some regions, special interpretations are made. One example is the soil drainage-drainability interpretation for soils on the lower coastal plain in North Carolina. In this case soil drainage classes are assigned according to soil characteristics, and the depth to a water table; drainability is a further interpretation based on soil characteristics. Drainage impacts productivity, site preparation, and trafficability during an array of activities. Drainability determines the spacing of ditches where drainage is necessary.

Another example is the regeneration interpretation for ponderosa pine in southern Oregon. Slope percentage, precipitation, soil depth, texture, and soil-rock volume have been combined to recommend a planting method -- either by hand or machine -- and the probability of plantation success based on soil and climatic factors.

As the intensity of forest practices increases, there will be a need for still more detailed soil intrepretations. Many of these will need to be developed through additional research, but with detailed soil surveys already in existence, additional interpretations may be made with considerable convenience.

In conclusion I would like to state that for many years, forest land management decisions have been made without knowledge of the soil. One does not have to look far before seeing mistakes that stem from this lack of information. With the application of the information available from forest soil surveys, sounder management decisions can be made.

Current Wildlife Habitat Inventory Techniques and Their Use in Habitat Management[1]

Richard M. Kerr[2]

Abstract.--A historic and contemporary review of habitat requirements shows that certain elements are essential to a useable habitat inventory. Some classifications will not yield needed habitat information unless they are designed to yield these elements. Many habitat evaluation systems can use pertinent inventory data elements once collected.

HISTORIC INTRODUCTIONS

There have been abortive attempts and all out efforts at inventorying the components of wildlife habitat for many years, mostly since the turn of the century in the United States. A conceptual system to measure or characterize these components in a way primarily meaningful to wildlife was probably not notably described in the United States until a third of the century had passed. Aldo Leopold described "Habitability Tallies" which recorded the occurrence of game required vegetative types on a large block of country (Leopold 1947).

SUBJECTIVE HABITAT ASSESSMENTS

Systems that are totally subjective in rating of renewable resource characteristics including wildlife habitat are usually developed to answer one or two contemporary problems and therefore, large geographic efforts of this type are usually not cost effective. If these inventories contain only a judgment of the examiner and do not record or evaluate factual ecosystem information, component information, they are of little future value. Evaluations or assessments made on a factual measurement of a component can be reviewed in the future for corrections of the evaluation system used. New and more correct systems may be applied to this original data at any time in the future. Habitat evaluation systems being developed today are tending more toward component measurement and recording and away from subjective field judgments.[3]

OCCUPANCY PREDICTABILITY

"Composition Tallies" and the "Habitat Tallies" (Leopold 1947) of Leopold are among earlier literature citations recognizing that wild animal species respond to existing vegetation composition and structure in different arrangements of interspersion.

In the western United States and other mountainous areas, in addition to existing vegetation, the second large factor determining animal use and occupancy of a vegetation type is its topography determined by local land form, that is, is the particular stand in a valley on a mountain slope or on an alluvial plain.

Ultimately the reaction to use or not use an area is greatly based on the phyisiognomy or visual characteristics of the vegetation and land form making up the site (Kerr and Brown 1976).

This preference for certain kinds of habitat based on phyisiognomy and in some cases specific composition is displayed by elk (Montana Coop Elk-Logging, 1976), Moose (Houston, 1968), and at the lower end of the vertebrate scale snakes display similar habitat selection by these factors (Reynolds, 1977).

In order to keep the functions of these two factors separate in our minds we might view vegetation structure as an indicator of habitat suitability, percent cover and composition of the vegetation as an indicator of habitat quality, and vigor (age and form class) as an indicator of apparent trend. Consequently, a piece of habitat may be suitable for a species, but offer varying degrees of quality which would affect the health and numbers of animal species occupying it.

It is evident that with smaller and more sedentary animals responding to phyisiognomy and

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[1]Paper presented at Integrated Inventories of Renewable Natural Resources Workshop, Tucson, Arizona, January 8-12, 1978.

[2]Richard M. Kerr, Wildlife Staff Leader, BLM, Denver, Colorado

[3]Shamberger, Mel. 1977. Personal Communication

composition, we may map their distribution by mapping the homogeneous cells which contain the proper phyisiognomy and composition determined by previously sampling similar cells for the occurrence of these species.

Although these inferences of similar animal occurrence in similar homogeneous land form and vegetation cells can be made for sedentary species, it is probably impractical to try this for more mobile and larger species. That is to say, that all cliffs suitable for nesting on the Colorado River will not have raptor nests on them, nor will all suitable deer winter range be occupied by deer. In the case of deer, only those ranges traditionally or habitually used will be occupied (Bertram and Rempel, 1977). With deer as with most ungulates, potential seasonal ranges and reproduction sites will generally be used only if individual animals have learned to use them (Houston 1968, Gruell and Papez 1963, & Seidell, 1976). Therefore, predictability of use by wild ungulates based on geographic habitat component occurrence is not at present an operational inventory technique and in my opinion, has little chance of becoming operational unless it is coupled with field inventory locating general herd and seasonal locations.

HABITAT TYPE AND RANGE SITE CLASSIFICATIONS

Many biologists are concerned with the propensity of soil scientists and plant ecologists to emphasize potential vegetation and soil delineation over the need for an inventory of existing vegetation.

The description of habitat types or range sites is helpful in management of the types and gives knowledge of potential. We will undoubtedly want to manage portions of all or some habitat types or range sites for disclimax or seral stages. This is necessary since many species of wild vertebrates have evolved using disclimax caused by fire, erosion, heavy grazing by large herbivores, etc., and these seral stages are required for their existence. Therefore, mapping by classification of habitat types or range sites does little to give us a starting point for management decisions, since we must maintain or proceed from existing seral stages to the desired stage. The desired stage may be either up or down the succession scale from the present situation. With just habitat type or range site mapping, we cannot quantify existing habitat for vertebrates, and therefore, don't know if we want more or less of each species of vertebrate. Since animals respond to existing vegetation, we must map homogeneous types if we wish to quantify habitat available for various species at present. If we map heterogeneous existing vegetation within one habitat type or range site, we have in effect mapped a mixture of existing animal habitats in an unknown proportion. The occupancy by animals and existence of disclimax or seral stages is not just a fleeting moment. In the pinyon juniper ecosystem as in many others, these stages occupy scores of years (Frischknecht, 1975).

If mapping of existing vegetation is not done, then a description of standard seral stages within each habitat type should be developed and each type mapped showing boundaries for these seral stages. Thence a standard description of ground cover and percent composition of plants by intercept transect for each seral stage would substitute for mapping of existing vegetation.

DATA NEEDED

Early efforts in the middle fifties exemplified by Milo Demming dealt with soil stability and vegetation as indicators of trend not only for livestock, but also for big game herbivores on public lands. His two phase rating system highlighted vegetational characteristics of quality, (composition), quantity (cover or density), or vigor (form class) and reproduction (age class)(Demming, 1957).

In the early 60's, the interagency range analysis handbook committee working in the central and southern rocky mountain areas required detailed mapping into "vegetative types" and subsequent recording of vegetative composition, density, vigor, and utilization for trend determination (Hill & Brandborg, 1960). The recommendations of this committee were formalized into U.S. Forest Service procedures for game range analysis. Cooperative actions were taken by other Federal and State agencies for their implementation.

Generally these same concepts of vegetation measurement for cover (density), composition and vigor have been used as inventory factors on key or critical big game ranges to the present time (USFS et al., circa 1970). While they have been in general use, little has been done with research indicating that size and shape and interspersion and ratios of feeding areas to cover areas are important for big game species.

The idea of sampling existing homogeneous vegetation types for small or sedentary animals and extrapolating to other like areas is new, but necessary. Likewise we feel for big game analysis that size, shape, and interspersion of seral stage areas within potential cover types if added to existing concepts already cited would give a succinct list of biotic and abiotic factors needed to inventory and analyze wildlife habitat:

- Homogeneous cell area - acres represented by the cell.
- Cell shape.
- Vegetation (existing).

1. Percent composition of the cover by species.
2. Total percent of cover.
3. Crown cover percent of shrubs and trees.
4. Structure of vegetation.
5. Vigor (age and form class if apparent trend is needed).

- Local land form.

1. Percent slope.
2. Aspect.
3. Elevation.
4. Land form description - i.e., valley, hill, mountain.
5. Topography (from USGS quadrangles).

- Animal occupancy and use within the cell.

1. Animal species occurring.
2. Use being made by each species.
3. Verification of species occurrence.
4. Tie to ecotones (neighboring cells).
5. Density (general abundance).
6. Special features: caves for bat roosts, highway bridges used for swallow nesting, watering areas, etc.

- Juxtapositional values determined by field inventory.
- Animal behavioral values determined by field inventory.
- A regionalized ecosystem (cover type) formed by a group of field cells having a similar vegetation potential.

SPECIFIC DATA USES

Several illustrations might be given as to how these measured and recorded ecosystem components might be used in managing big game habitat. References for Big Game rating criteria that follows are: Demming, 1957; Hill and Brandburg, 1960; Houston, 1968; Kerr, 1977; Montana Study, 1976; Reynolds, H.G., 1966 & 1962.

A preliminary to rating big game range (Figure 1) would require that the rater determine which species the range is to be rated for (as all have different optimum requirements), what season the range will be rated for (as food and cover requirements change with the season) and whether or not water is adequate on the range.

Based upon the information collected during the inventory, a key species of grass, forbs, or browse, is rated for age and form class and is either satisfactory or unsatisfactory depending on established criteria for these rating systems.

Big Game Range Ratings

I. Vigor Rating (Information for Rating taken from Form 6630-3, Site Inventory Forms). Rate a key species of grass, forbs or browse.
For Browse Ratings use 6630-3 or Site Inventory forms.
For Grass Ratings use Site Inventory Information.
For Forbs use Site Inventory Information.

A. Age Class
[ ] 1. If satisfactory enter 10 pts.
[ ] 2. If unsatisfactory enter 5 pts.

B. Form Class
[ ] 1. If satisfactory enter 10 pts.
[ ] 2. If unsatisfactory enter 5 pts.

II. Forage Quality Rating

A. (Rate range that is least in supply or critical to the big game species; if two or more seasonal rsnges are critical rate all that are and divide by the seasonal ranges rated.)

B. Using a locally constructed table of desirable, intermediate, and least desirable plants by species and use percent composition listing for habitat site or mean composition of a group of sites determine if:

20 [ ] desirable species are present in quantities over 45%.
15 [ ] intermediate and desirable species make up at least 50% of the composition with desirables at least 15%.
10 [ ] less than 50% but more than 25% of the composition is made up of desirable and intermediate species.
5 [ ] undesirable species are 75% or more of the composition.

III. Food Area to Cover Area Ratio

A. Using the vegetation map or aerial photos list those habitat sites opposite their acreage which are considered food areas and similarly those which are considered cover (all types including fawning cover, escape cover or thermal cover). Use areas known to be within the <u>occupied</u> herd area only.

DEER

20 [ ] herd area being rated is composed of 60% food patches and 40% cover (trees or shrubs in groups and over 20 ft. high are mainly considered cover types).
15 [ ] cover or food area percentages vary 10% - 20% from above.
10 [ ] cover or food area percentages vary 20% - 30% from above.
5 [ ] cover or food ares percentages vary 30% + from above.

ELK

20 [ ] herd area being rated is composed of 50% food patches and 50% cover patches.
15 [ ] cover or food area percentages vary 10% - 20% from above.
10 [ ] cover or food area percentages vary 20% - 30% from above.
5 [ ] cover or food ares percentages vary 30% + from above.

ANTELOPE

20 [ ] Reproduction cover is abundant on fawning areas.
15 [ ] Reproduction cover is adequate.
10 [ ] Reproduction cover is lacking.
5 [ ] Reproduction cover is almost totally absent.

MOOSE

20 [ ] Herd area being rated is 15% willow, 25 dry parks or shrub ares, 20% aspen and 40% conifer.
15 [ ] Any one of the cover and food types above varies more than 5% from the above.
10 [ ] Any one of the cover and good types above varies more than 10% from the above.
5 [ ] Any one of the cover and food types above varies more than 15% from the above.

IV. Forage Area Size

DEER AND ELK

20 [ ] Food patches 20-60 acres in size.
15 [ ] Food patches more than 60 acres in size, less than 1/5 mile across.
10 [ ] Food patches 1/5 to 1/2 mile across.
5 [ ] Food patches greater than 1/2 mile across.

MOOSE

20 [ ] Willows continuous over area to be rated, some major patches 800 yards or more across.
15 [ ] Willows mostly continuous, broken in a few places, major patches 400 to 800 yards across.
10 [ ] Willows periodically broken at almost regular intervals, major patches 200 to 400 yards across.
5 [ ] Willow patchy, more broken than continuous major patches less than 200 yards across.

V. Disturbance or Interface Rating

A. Taken from census or demographic trends, aerial photos, 6602-21. These influences can be observed in a general way and are a subjective judgment of the rater, but where major interferences or disturbance is indicated it should be narratively explained.

20 [ ] Historic crucial, reproduction and/or migration areas are undisturbed by an influx of people and/or their facilities with little change in the last 10 years. Few if any conflicts or hazards are documented on Form 6602-21.

15 [ ] Historic crucial, reproduction and/or migration areas have been slightly disturbed in the last ten years; only a few new roads or facilities have been constructed; a small number of conflicts or hazards are obvious enough to be documented on Form 6602-21.

10 [ ] Historic crucial, reproduction and/or migration areas have been noticably disturbed in the last ten years. Conflicts and hazards could easily be identified and documented.

5 [ ] Historic crucial, reproduction and/or migration areas have been severely disturbed in the last ten years. Many conflicts and hazards could be identified and documented.

RATINGS	SUM OF POINTS
Good	80 - 100
Fair	60 - 80
Poor	50 - 60
Bad	30 - 50

If the rater for purposes of evaluating range conflicts only desires to rate big game range based on vegetation only then ratings for Vigor and Forage Quality only may be used and multiplied by a factor of 2.5 for the rating score.

For non-forest or non-tall bush types and antelope and bighorn sheep, do not use the Food Area to Cover Area ratio or the forage areas size ratings. Multiply the total score of the other ratings by 1.67 for the condition rating.

Figure 1.--Big Game Range Ratings

Next a forage quality rating is given using the percent composition displayed on the vegetation inventory and compared to a locally constructed table of desirable, intermediate and least desirable forage species. These tables must be constructed by big game species and season. Only the limiting seasonal range need be rated.

Then using cell description and acreages from the vegetation inventory, list and sum all cells considered food areas and then all that are considered cover areas. A list of criteria giving rating points can then be developed from these ratio percentages.

A forage area size rating may be given again by species requirement and appropriate rating points given.

With the rapid population growth of western states, human disturbance, both directly and by the construction of facilities, may be a factor and a semi-subjective rating may be given here. Although it may not be desirable to enter a subjective rating, so long as elements are rated separately, it can easily be removed from consideration if so desired. If these classes are then summed, an overall rating can be obtained.

Another example of the application for the data shown would be determination of suitability. One might give a rating of suitability of a particular piece of range by determining the average seasonal daily movement of the species with which he is concerned, and then using the radius, circumscribe a cirle of daily range on the inventory, overlay or map. When this is done, a table giving required sites for the species is applied by comparing the types needed with the types intersected by the circumscribed circle, then a formula for suitability rating may be applied (Figure 2 & 4).

Species Habitat Suitability Index

Numbers of necessary standard sites intersected.

Numbers of necessary sites.

Answer of 1 is necessary to proceed to rating table, less than one is unsuitable.

Required types are all present and make up 100% of the range circle	= highly suitable
Required types are all present and make up 75% - 100% of the range circle	= suitable
Required types are all present and make up 50% - 75% of the range circle	= moderately suitable
Required types are all present and make up 25% - 50% of the range circle	= marginal

Species Interpersion Index

Total % of length of inventoried needed types = $A_1 - A_x$

If three inventoried types are needed, they would be presented as:

A_1, A_2, A_3

These values are placed over the % of each type needed for optimum habitat = $N_1 - N_x$

$$\frac{A_1, \; A_2, \; A_3}{N_1, \; N_2, \; N_3}$$

Substitute values such as:

$$\frac{25\%,}{30\%,}\;\frac{25\%,}{30\%,}\;\frac{10\%}{5\%}$$ [doesn't have to be 100%]

$$\quad -5 \qquad -5 \qquad +5$$

Subtract as indicated.

Total difference is -10 [don't count pluses]

Fractions equaling 0 - 20% variation = good
20 - 40% variation = fair
40 - 60% variation = poor
60+% = bad

Figure 2.--Indices obtained.

Other information used for management would be a species interspersion index. A seasonal table of required habitat sites would first be constructed (Figure 3). Then using BLM inventory method, use the overlay showing "sites" or habitat sites typed out. From the table of average daily ranging distance, set the movement radius to scale.

Locate the center of activity or center of ranging area. In the arid and semiarid areas, this will be the watering area, in others it may be the bedding area, thermal cover area, etc. From this center circumscribe a circle with the radius set on the compass as above. If the whole actual or

Land form and vegetation types (standard habitat sites) needed for

Mule Deer (species) for winter season

for Southern Rocky Mt. physiographic region.

1. Water (enter water if daily or period live water is required)

	Enter % of Total Habitat for Optimum
2. South and/or West* facing shrub (forage)	30%
3. South and/or West* (cover) facing conifer	30%
4. South and/or West facing (bedding) open timber w/shrub understory	5%
5.	
6.	

* a timber type with 50% shrub understory could substitute for these two types - snow must be less than 20 inches in depth.

Figure 3.--Habitat Site Requirements.

potential range is to be deliniated, then the maximum distance of daily ranging may also be circumscribed. Using the circle circumscribed for average daily ranging distance, mark the boundaries of types where they cross the circle.

Now count all boundaries of necessary types that are crossed and record.

From the center of the circle construct lines through each vegetation boundary intersection with the circle. Measure the angles formed by these rays and record them as angles of their appropriate type. Compute the percent each angle is of the whole using the following formulae:

X = ∠ of rays projected from circle center encompassing type intersections and measured with a protractor.

$\frac{X}{360}$ = % of circle (or chance of intercepting a needed type).

Physiographic Region Southern Rocky Mtns. /1

Season	Species	Daily or Weekly Ranging Distance /2
Winter	Mule Deer	½ mile diameter /1
Spring		
Summer		
Fall		

/1 Footnote Research Reference.
/1 Dasmann, William 1971, Wildlife Management Institute
/2 Use weekly and so mark if species uses expanded range.

Figure 4.--List of Daily Species Movements by Season.

These types are then entered into a formula using inventoried types over needed types and a rating system for interspersion is applied (Figure 2).

An edge index is obtained to compare one site to another for edge values using as an index the sum of required standard site boundaries crossed by the circumscribed circle using average daily ranging distance as a radius.

As can be seen from the above examples, a great many evaluating systems can be applied using inventory information which will yield: condition and trend information for most animal species, limiting factor information, habitat comparison from one site to another, etc. These evaluations, however, can only be made if integrated surveys include the correct data elements necessary for them.

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The National Heritage Trust Program: Information Systems for a National Objective[1]

Susan D. Smith and Paul Pritchard[2]

Abstract.--The President's request to the Department of the Interior to prepare a proposal to protect our Nation's natural and cultural heritage conveyed one of the most important decisions addressing information systems for natural resources to develop a comprehensive effort to identify our natural and cultural heritage, and to immediately begin the protection of that heritage. The charge to develop a comprehensive effort has evolved into the National Heritage Trust Program proposal. This paper describes the proposed program, and addresses some general policy conclusions and important issues which the information system that supports this program must include.

When the President first asked for the Department of the Interior to prepare a proposal to protect our Nation's natural and cultural heritage, there was little explicitly stated about the need to understand information systems efforts that are being described here this week. However, in his five paragraph statement about the National Heritage Trust Program that he was requesting from the Secretary of the Interior, the President conveyed one of the most important decisions that will be stated addressing information systems for natural resources. This decision was the development of a comprehensive effort to identify our natural and cultural heritage and to immediately begin the protection of that heritage.

This paper is an effort to describe first the National Heritage Trust Program in its current state and secondly what overall policy objectives apply to the supportive information systems. It is important in addressing this topic to understand that the President's message was delivered as part of the Environmental Message of May 23, 1977. The development of the actual proposal has just been completed and was reviewed by the President the week before Christmas. It will take six months to actually develop the final concept for the information systems that must serve the National Heritage Trust Program. That concept, of course, will address specific policy objectives of the Heritage Trust Program, and much more--objectives that I will address in a latter part of this paper.

WHAT IS THE NATIONAL HERITAGE TRUST PROPOSAL

The President specifically asked that the National Heritage Trust Proposal be developed by the Secretary of the Interior to address the following 7 items:

- A systematic program for the collection and updating of information and data relevant to the identification and protection of National Heritage areas, which is coordinated with other State and Federal programs.

- Criteria and appropriate procedures for identifying, selecting, acquiring and protecting National Heritage areas so as to assure the continued quality of life of our citizens today and in the future.

- Provision for the immediate acquisition of the most significant and endangered National Heritage areas and examples of natural ecosystems.

- Provision for long-term planning and periodic review which will assure that areas which need protection are identified.

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[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan 8-12, 1978.

[2]Office of Systems Management and Deputy Director for Programming, respectively, USDI, Bureau of Outdoor Recreation, Washington, D.C.

- Appropriate means to insure protection of areas in order to assure their preservation and continued value.

- Ways to insure State and citizen involvement in the determination, acquisition and preservation of National Heritage areas.

- A program for identifying and protecting significant National Heritage areas within the jurisdiction of Federal agencies.

Because of the magnitude of this program and yet the President's dual concern that this be prepared in 120 days, a task force was assembled headed by the Department of Interior under the leadership of the Secretary and the Assistant Secretary for Fish and Wildlife and Parks. The Bureau of Outdoor Recreation's assignment was to assemble people who were best able to address this issue. It is important to point out here that no funds or personnel were provided for this program. All of the talent that was included was provided by Federal agencies and some 50 private and public interests that really saw the need to be involved in this effort. Agencies included the entire range of resource agencies of the Federal government: the National Endowment for the Arts, Bureau of Land Management, the National Trust for Historic Preservation, the Library of Congress, the Smithsonian Institution, U. S. Forest Service, Fish and Wildlife Service and National Park Service, and even the Office of Management and Budget. The private interests included the American Rivers Conservation Council, the Sierra Club, the Conservation Foundation, Preservation Action, and a number of other interests who were clearly committed to the question of protection of our Nation's natural and cultural heritage.

In the 120 day period, the 100 representatives of these private and public interests were divided into three basic teams: a natural team, a cultural team, and a protective methods team. The Natural team decided at the outset that they were concerned about four basic areas of interests--ecological resources, geological resources, scenic resources and wildlands. The Cultural team was concerned about a program that has existed for some 10 years under the National Park Service's Office of Archeology and Historic Preservation. That program under the Historic Preservation Act of 1966 involved 5 basic categories of resources--sites, buildings, districts, objects, and structures. In addition, that team concluded that the cultural resources of this country should include three other areas of concern for the Office of Archeology and Historic Preservation. These three additions included networks of features centered around a central theme, cultural landscapes or the setting around a specific cultural resource, and neighborhoods.

The proposal that has been approved by the President will be discussed and announced later this month. Therefore, little can be presented now about the final conclusions made by the President and the Secretary of the Interior. However, it is important to point out some general conclusions as to the future of the program. First, part of the recommendations made by this group of public and private interests included the development of a detailed classification system for both natural and cultural resources. Second, there was a clear consensus that an information system should evolve from the classification of these two types of resources. Third, there was a clear commitment that natural and cultural resources should be addressed by a single agency under a unified effort. And fourth, there was a commitment that this must be a national program in terms of levels of effort, and a clear mandate in terms of time to protect these resources.

THE INFORMATION SYSTEM

One of the critical objectives of the Department of Interior when the Secretary announces the program will be to develop an information system which serves the needs of the Nation to identify, select and protect our cultural and natural heritage.

More importantly there are a number of policy conclusions that we have already discussed that will be addressed by the information system. For example, there was a commitment that the classification system should be evolved before there is development of the information system. This was concluded because of the need to assure that systems, in terms of hardware and software, do not dictate policy objectives.

In the same sense, there is a need for the new agency that will be overviewing the process of protecting our Nation's cultural and natural heritage to assure that it links in other programs and objectives that are related to the development of this information system. We must therefore conclude that there are some overriding issues which our information system must address in addition to the general policy considerations stated above.

The first overriding issue is that the information system must be descriptive in terms of quantification. This is essential in that decisions made about the allocations of dollars and resources in the future will be constantly compared to other programs and objectives. Whether we are buying acres of land or counting numbers of eagle nests, the senior policy decision makers will always be interested in knowing the specifics, in terms of numbers, about our particular program. Therefore, we must be

concerned about being able to clearly quantify any resource that might be protected.

Secondly, as an outgrowth of the President's clear and important message, there is a need to assure that there is no additional proliferation of information systems or programs. For example, during the development of the National Heritage Program, we identified over 100 federally instigated natural resource inventory programs being conducted by over 40 separate Federal agencies. It is essential that we assure ourselves that we are not merely creating an additional information system. Yet, at the same time, it is essential that we not allow the clear mandate and objective of the President to be ruled or controlled by information systems that serve other objectives.

A third overriding issue our information system will address is to assure that the information gathered will serve management objectives of the organization as well as day-to-day operational responsibilities. Because there will be an allocation of dollars, human resources, and other resources of the public, there is a need to assure that we are able to manage these resources and to assure ourselves that we are expending them in the most efficient manner. The President specifically stated that his concern in the development of the heritage program was that there was a "proliferation" of Federal programs that was neither efficient nor effective. Our concern is that as part of the management objectives of the organization, we are able to integrate the heritage program into the broader agency goals.

A fourth issue is to assure that we are able to show that this program clearly is addressing specific needs of the Nation. What this means to us is that the information system that we would deal with would be geared towards consolidation of information collected and analyzed at the State level. We should, therefore, not just repeat the information that is assembled at a State or other level but rather be able to aggregate it and make recommendations based upon analysis of that aggregate information for our national effort. In this sense, we might be addressing the overall question of quality of life as it relates to natural and cultural resources. For example, our objective might be to assure that we are actually protecting all of our Nation's natural and cultural resources as you look at it at the "macro" scale while the States themselves are protecting individual resources at the "micro" scale.

A fifth objective relates to the previous concern and that is that we tie this effort into the broader concern of the quality of life as we deal with the social and economic objectives of national policy. For example, it would be useful to know how many resources in different areas of the States are being protected, especially as they relate to development patterns, the change in the value of land, the objectives of people in their interest in providing volunteer services to protect and manage specific resources, and other indicators of social and economic commitment in this country.

Finally, we may in fact be concerned about assuring that the information system that we will be developing will address international objectives of environmental protection. At this time, a number of different interests are preparing information systems at an international scale. They not only include the United Nations and the International Union for Conservation of Nature and Natural Resources, but also organizations that are interested in environmental protection as, at best, secondary objectives. For example, the Organization for Economic and Common Development now has a working group addressing the impact of development on the environment. This organization on which our Deputy Director, Paul Pritchard, serves as the U. S. Representative, is concerned with identifying what key environmental factors are important in decisions relative to development. The area of international programs, as we all know, is very important if we are to assure that protective efforts in various countries are reinforced and complemented by protection in other natural resource areas.

Panel III — Need for Integrating Inventories: Moderator's Comments

H. R. Glascock, Jr.[1]

There is probably no subject in forestry today more urgent and complex than that of integrating resource inventories. The lack of integrated resource information not only makes implementation of multiple use programs extremely difficult or impossible, but also gives the public the image of a disorganized, ineffective, uncoordinated resource effort. For many years foresters have been developing and refining inventories of timber inventories. By and large today we have a fair amount of meaningful inventory data on timber. Likewise, from time to time inventories of water resources, of soil resources, of range habitat and of recreation opportunities have been initiated and published. But in these latter undertakings the methods and techniques often have not reached the stage of refinement we have for timber.

So why not, why don't we have multi-resource data for a given area which is well integrated and highly meaningful? My impression is that the responsibility for gathering resource data is specific for one resource and for one agency, but there is no driving force which brings the agencies together such as Congressional direction. The Soil Conservation Service inventories soil and water, the Bureau of Outdoor Recreation inventories recreation, the Forest Service timber and range, the National Park Service parks, and so on and on. Maybe what we need is one agency to do all the inventory work and report back to the individual agencies the resource situation. At least the agency orientation is one of our inventory problems.

Another is, I believe, that we don't know what is needed in inventory work. In what detail is resource information needed? By what geographical and ownership units should the data be available? How often should the inventory be repeated? And what does the integrated inventory term really imply? In other words, as you discussed yesterday, what are the information requirements? These must be known before an integrated inventory can be initiated to meet specific needs.

A third point and a critical one is how to do integrated inventories--not just physically--but how to organize and carry on an inventory that meets a need. From what you have already said, I'm not sure you know yet how to make such an inventory. But if you are to meet a need, you better get on rapidly with designing an efficient and meaningful method. Lacking this you'll never, in our lifetime, come up with the resource data so we can relate it to a national, regional, or local need.

Having said this, let's look at the other side of the coin: do we know what the need is? I don't think so--we know we need something so we can relate one resource to another and evaluate its status quantitatively and qualitatively. But beyond this what do we really need? Do we know if the supply of a resource is changing, what its productivity is, what its characteristics are, what its size is, etc. I suppose the easiest way is to say, "Yes, we need all this and more, too." But we must realize our financial resources are, and always will be, limited, maybe more so in the future than now.

I guess what I've been saying so far is that we have a big need now to determine what our job is and how to do it most efficiently. Obviously, we must define and thoroughly understand the need soon--or the public is going to say: let's get someone or a new organization once removed from those who are now fumbling with the job.

Let me ask, for example, is there any reason why the Forest Service, the Bureau of Land Management, the states, and private owners have basically different systems for resource surveys? Perhaps their needs differ somewhat, but isn't it possible to use one system to meet many needs?

The Resources Planning Act of 1974 calls for much resource data to be obtained through inventory surveys. Planning is just as good as the information that goes into the plans, or that comes in from an integrated inventory. The RPA is certainly one of the most significant and also most demanding pieces of forest resources legislation of this decade, maybe of this century. If the Forest Service is to do its part, the other agencies must be working with it in developing resource information--leading to a truly integrated effort, an

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integrated analysis and evaluation, and an integrated plan. It is quite likely that RPA's of a sort will become a way of life for all natural resource programs and agencies in the not too distant future. This alone means that we must not only understand the need, but that we must define it in a way that is useful. We know that resources are interrelated--water affects timber, soil affects water, range affects soil and water, and so on. So our inventory must be interrelated too.

So far I've talked only about plant life, but animal inventories are also a part of our problem--our need. Animals are just as much a part of the resource picture as the trees and grass and water on which animals depend. Thus our need is broad and variable.

Before we get on to the several papers which are to discuss these subjects this morning, let me ask what I believe are some of the most pertinent questions to be considered:

(1) What kind of a policy do we need to achieve one focal point for all of this inventory need?

(2) What policy do we need to get an integrated resource survey on the ground--not five agencies doing their thing individually?

(3) Should we have separate inventories for plants and animals?

(4) Do we depend on the RPA to define our need, or do we need some other mechanism to arrive at an agreed on type of survey and the kind of information to be obtained? Who is to take the lead?

(5) Last, but not least, is this to be a professional job, done by and for professionals? Or is it to be a reaction to popular demands done by Johnnies-come-lately from pressure groups?

With these questions before us, let's see what our program speakers have to say.

National Integrated Inventories — Is What You Need What You Do?[1]

Thomas E. Hamilton[2]

Abstract.--The need for inventory integration is to describe resource and resource use interactions. Our approach should be to design a program which incorporates what we now know and which allows the flexibility to add new techniques as they become available.

National integrated inventories are needed--agreement on that is strong. At least its strong until we begin to identify the integrater and the integratee; at that point--whether we are talking about objectives, agencies, or resources--the discussants get a little cautious. The question "Is what you need what you do?" becomes very real.

Those of you who have been involved in the tasks of conducting resource evaluations for national and regional assessments have long felt a need for integration of resource inventories. And in recent years, this need has become more directed, especially for Federal agencies. For example, the Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976 explicitly direct the Forest Service to assess the <u>total</u> renewable resource situation on <u>all</u> forest and range lands. I emphasize the words <u>total</u> and <u>all</u> because they represent two elements in the question we should consider first: What does inventory integration mean?

Since we have several resources and uses involved, many appropriate inventory techniques available, and many groups participating, inventory integration can involve many things. All are related; some more closely than others. One kind of integration involves successive stages of inventory sampling. Usually, this sort of integration is accomplished in designing the inventory; for example, aerial photographs may be used to stratify areas from which a ground sample is selected. But suppose these two stages are performed by different groups, and further, suppose that the groups have different purposes for conducting the inventory.

This leads us to a second kind of integration, multiagency or multigroup. We in the Federal Government, in particular, are continually faced with the need to coordinate data obtained from other agencies. This is not just a matter of inventory efficiency; we badly need a common set of inventory statistics on which to base assessments, programs, and policies.

Often, the problem in integrating agency inventories is one of designing an inventory capable of meeting different objectives or purposes--here is a third kind of integration: multipurpose. We need not go outside our agency to demonstrate the complexities here. The problem of integrating information from inventories designed for regional and national assessments with information from those designed for management activities is a familiar one to most Forest Service inventory specialists. But when we do go outside our agency, the problem is even larger because the purpose for the same type of inventory of the same resource is often different.

The next kind of inventory integration is one we talk about a lot these days, and may be the primary one which the planners of this workshop had in mind. Multiresource inventories are a popular topic--although the reasons for needing them may be even less clear than the subject itself. Coupled with the multiresource concept is that of multidisciplinary approach. The difference here may appear subtle, but there is a difference. Bringing together knowledge that can be used by all disciplines is difficult. Not only do we have to overcome the problems of prejudice and limited vision that have developed over long periods of time within disciplines, we also have to overcome the problem of communication. To some extent each of our disciplines is isolated by its own unique language and terminology. We still need to develop a means to cope with problems across disciplinary boundaries.

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[1] Presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Jan. 8 - 12, 1978, Tucson, Arizona.

[2] Group Leader, Resources Evaluation, Forest Resources Economics Research, Forest Service, Washington, D.C.

Overlying all of these kinds of inventory integration is another kind of integration question: Are we talking about combining the inventory processes themselves, or are we concerned with putting the results of the inventory together? The answer is not clear-cut, and may be different depending on who the decision-maker is. I will consider this in discussing the question: Why integrate?

Yesterday, we talked about resource information requirements. But in what sense and for what purpose should these requirements be considered for integrated inventories. What is the problem that an integrated approach to resource inventories will solve?

Why Integrate?

Why should inventories be integrated? One of the most common reasons given for collecting a variety of inventory information simultaneously--that is, a single group collecting multiresource data--is inventory efficiency. But this is not the reason for integrated inventories, but rather a way to effectively accomplish them.

In addition to efficiency, we hear many other reasons for integrating inventories such as: provide a common data base, provide for data compatability, improve total resource information accessibility, facilitate updating of resource information, improve the precision of assessments, provide additional resource detail, promote consistency in programs, and provide a single best estimate of the resource situation. All of these reasons contain elements of what we are really trying to accomplish in an integrated inventory program, but none of them state the problem directly.

In the not-too-distant past, our inventories were conducted to provide a data base for evaluating the current and future resource situation. In fact, this is still largely what we provide. But this is not enough today.

America has only recently developed an appreciation for the limits of environment. By now, everyone is aware that the expansion phase in man's development is over. In today's world, our future well-being is primarily a factor of the harmony we are able to achieve with environment, other people, other life forms, and our physical surroundings. That harmony we desire will come about in large measure through appropriate integrated use of land and resources.

Another problem is that science developed along functional lines. Scientists were trained in economics, in applied biology such as forestry, in biometrics and mathematics, in physical sciences. Now we are confronted with a new reality, that the world is a limited island in space. This means that science, as well as society, must alter its approach. Our major problem today is that we have to address environment and effective integrated multiple use of land and resources. This calls for bringing together knowledge from all disciplines.

The problem we are addressing can be stated in rather simple terms. If the concern of society is both with harmony in the environment and with the supply of renewable resources, then we have to inventory those resources in the context of environment. Since all things in nature are to some degree interrelated and interdependent, our approach to inventory must allow us to describe resources in a particular time and place in a way that reflects interactions or allows us to describe the products of interaction.

Our inventories cannot be designed solely for current situation reporting. They must show changes and why the changes occurred. We must be able to predict, in total, the outcome of man's resource use or resource manipulation activities.

How Do We Approach the Problem?

How do we approach the inventory task when this is the objective? We can examine the answer to this question from at least three points of view:

1. Sampling and measurement
2. Biological and ecological
3. Social economic

Sampling and Measurement

In sampling and measurement, we do appear to have a starting point. From an overall sampling point of view there is a considerable body of knowledge on which we can draw.

We also know how to approach the problem of interactions. We should use a multiresource approach; that is, to measure all resources at the same points or places so we can directly relate the information and observe the products of interactions.

I recognize, as I am sure you do, that in many cases we don't know what to measure to describe some use opportunities. Many of our techniques for measuring grass, forbes and browse cover and other less quantifiable forest attributes are crude to say the least. I am only arguing here that we do know something about how to approach the task. We can begin; begin and add new techniques as they become available.

Biological and Ecological Aspects

It is surprising to many that after 200 years as a Nation we still don't know much about habitat requirements of many rather important plants and animals. As many European scholars have noted about us, our country was so large and rich in natural resources we paid little attention to details of nature. Not until we began to feel people pressure on our land, largely in this century, did we develop a concern for nature.

Ecological concern is even a later development. We find land managers today asking that we inventory resources in the context of land as environment. However, as of yet we do not have an adequate way of classifying land as environment. This is not to say that the need for such a land classification has not been recognized. Geographers have been wrestling with the problem for over a century. Plant ecologists have been particcularly active in this century and especially in the last few decades trying to categorize land in terms of vegetative cover. Now scientists of all disciplines are in the act. However, we still lack sufficient understanding of all the interactions in nature to come up with a good land or space classification system that meets a broad spectrum of needs. It appears that for some time we will have to accomodate ourselves to a number of partial systems which meet specific purposes.

In addition, when we try to deal with resources in either a natural or social ecological sense, we find that many attributes and emergent properties can best be handled through inplace or map data. How many resources interact and what the interactions produce is a factor of spatial arrangement and juxtaposition. Thus our approach to resources evaluation must provide for intergrating data derived through on-the-ground sampling with that derived from maps.

Further, some interactions are affected by time. Plant communities change over time. So do animal and people communities and these changes affect resource production, use, and interactions. Our inventory approach must enable us to deal with change over time and interpret time related interactions.

Social Economic Aspects

From a social-economic point of view two problems have to considered in planning for resources evaluation. The first is to spell out the questions to be answered by the inventory effort. We are concerned about the use of land and resources by man. It is the responsibility of the social scientist to lay out the questions to be addressed, determine how each is to be answered, and the information required to answer each question. Economists alone cannot do this job, they must work with inventory specialists. But the economists must take the lead.

The second problem derives from the nature of social economic questions. Most of these questions are of the type that the answer varies with scale.

The answers to questions concerning resources will differ depending on whether they are being addressed at the local, state, regional or national levels. Thus our inventory program must be designed in such a way that data are collected and compiled in a manner that will provide this capability. We must be able to work from the same data base and aggregate to various levels.

What Do We Do Now?

How do we approach the inventories of renewable resources of forest, range, and related lands? How do we go about the job of inventorying resources within the context of environment when we lack some understanding of environment and of many of the resource components of enviroment? We can no longer wait. We must look critically at what we do know and see if we can put together an approach that allows us to build as we go, integrating new information and capability as it becomes available.

It appears, from looking at our experience, that it will take some time to overcome disciplinary, institutional, and single objective barriers. In our organization, our biggest effort of this type has been to establish a Renewable Resources Evaluation Techniques Program at our Rocky Mountain Station in Fort Collins, Colorado. This Program has been in operation for over a year and it appears that we have some excellent opportunities to overcome problems of communication between groups.

I'd like to emphasize integration of information. If we are to build a resource information base adequate to meet the analytical needs of the Nation, we must be able to integrate information collected by the

Forest Service with that collected by BLM, BIA, State organizations and other groups. In the process we will enhance analytical capability for all groups at all levels. So we are really talking about all the kinds of integration I discussed earlier.

I submit that what we don't know about many of our resources, how they interact, and about our environment generally, is ominous. We need a lot of research and technical discussion to clarify the different aspects of the problem we are concerned about. At the same time, we must use what we do know to launch resources inventory programs that are dynamic in nature and which could contribute immensely to our understanding of the world we live in and what our future will bring. It seems to me that we have the knowledge required to modify and expand our inventory program in a way that we can add new information and incorporate new techniques as they become available. We need only to design our program to accommodate these needs.

Regional Integrated Resource Inventories — A Place for Coordination[1]

William J. Pulford

Abstract.--Regional Integrated Resource Inventories can be useful to land managers if they recognize what items need coordination before they start the Physical Inventory. Without adequate coordination and preplanning, Regional Inventories have little potential for success.

INTRODUCTION

Regional Resource Inventories, in my opinion, have not been as productive as they might have been in resource management. In fact, managers tend to be reluctant to use them because of problems traditionally associated with regional type inventories. I believe they have potential to help resource managers do a better job. My definition of Regional Integrated Resource Inventories is as follows: Inventories conducted on large geographical areas, i.e., multi-county or larger, encompassing several resources designed to meet agency needs for resource information. The information collected in a regional inventory must recognize agency objectives, issues and problems.

I believe there are several areas of regional inventories that will be productive to discuss. I plan to cover objectives, procedures and benefits of Regional Integrated Resource Inventories.

The first objective of integrated resource inventories is to consider agency program objectives and priorities. They should be structured so data collected provides a base from which to consider these priorities. It does little good to collect information on resources or programs not suited to agency priorities. It is also surprising at how many times this occurs. This is especially critical in light of limited time, manpower and dollars. I believe land managers can do a much better job if they will think out agency priorities and programs before starting inventories; and then do a skillful job of collecting information that reflects them. Local inventories are, in many cases, structured around local objectives that are not always the same as national objectives. This leads to problems and if agency priorities are missed, we can and usually do get overlapping or useless or missing data. The first objective then is to consider national objectives, problems and issues and include those objectives with local needs.

Regional inventories must provide a basis for resolving conflicts within programs. Preplanning will help resolve some of these areas and indicate what kinds of data should be collected. By collecting data that highlights known conflict areas, it should provide resource managers a base for better decisions. This objective in integrated inventories is to provide data for known conflict areas; and as far as possible to spell out those areas before starting the actual inventory process.

Resource inventories should provide the correct data for managers. Gathering proper data would seem to be a relatively simple matter and one that would evolve naturally from any resource inventories. However, this is usually not the case. Accurate data tailored to the type of decision to be made is important. Resource data not tailored to decisions is useless. As an example in inventory, if resource mapping units are not of the correct size, data may be too detailed or it may be too general. You must tailor your regional inventory procedures to the types of decisions your agency or company usually makes. If your management decisions involve hundreds or thousands of acres, regional inventories based on mapping units 100 acres in size are too detailed for your needs.

Coordinating basic data with other federal and state agencies, I believe, should be another objective of integrated inventories. In a

[1]Paper presented at Integrated Inventories of Renewable Natural Resources, A National Workshop, Tucson, AZ, January 8-12, 1977.

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well-designed inventory, information could be shared with other agencies and could help data coordination. This objective will become more critical as we move to automate resource data. As one agency builds its data elements and definitions these definitions should, as far as possible, be shared with others.

Cost effectiveness is another objective. Regional integrated inventories have the potential to be more cost effective than small locally tailored inventories. This relates to the point above about collecting correct and needed data, but it also relates to the need to collect similar data in a number of different units. The data could be similar and sampling techniques can be applied and if similarities exist this could reduce the cost of inventories, especially over large areas, i.e., multi county or larger.

In addition to cost effectiveness, the preplanning necessary to carry on adequate regional inventory can also be used as a basis for allocating scarce dollars and manpower. If we have done an adequate job of analyzing program priorities, issues, and needed data, then we can allocate dollars and manpower to critical areas.

The last objective is to use integrated resource inventories as a basis for interim critical management. This objective would not be present in all resource inventories. However, with good preplanning, integrated resource inventories would provide an excellent base for interim management until the necessary planning decision process has been accomplished.

I have tried to cover several objectives which I believe are important in regional inventories. Now I would like to discuss procedures that could be used to meet these objectives and carry out effective inventories.

PROCEDURES

First, I would like to define coordination since I believe it is particularly important in regional type inventories. I define coordination as applying certain actions or controls to give direction to an otherwise uncontrolled series of events. Why is coordination so important in regional inventories? Because it is the basis to select the geographical areas for inventory and program priorities and issues. After you have coordinated the above, the inventory can be tailored to meet issue and data needs and be conducted on logical and critical areas. In coordinating issues you should also ask the question, "Do the issues needing data cross logical regional boundaries?" If the answer is yes, then you must determine how the issues affect the collection of data. Does data need to be collected on several "regions" or only within a small area? Will the data collected have impacts on other issues within a region or other regions? These are the types of questions that must be answered.

A second step in the process is matching inventory approaches with the issues and problems. This relates to the objective of defining issues and problems and is usually overlooked in regional inventories until the collected data is analyzed. At that time it usually becomes apparent that the data collected does not match the decisions to be made. In other words, early on you must establish some relationship between the issues and the inventory approaches you intend to take. Your procedures should be tailored to the specific situation. This is not to say to collect only information relating to expected issues and decisions. I am sure many of your agencies have standard inventory procedures that you are required to follow and information you are required to collect. However, I am saying to plan early to avoid coming to the end without the data you need.

Next, you should define the scope of the inventory. It involves all the points brought out in the other procedures. You need to look at agency programs, priorities, regional issues, local problems and, of course, your resource inventory needs. I am not neglecting actual resource inventory needs; I am only saying what dâta you actually collect about the resources depends a great deal on situations extraneous to the resources themselves.

Next, define your geographic unit. Definition of an area or areas depends upon: the resources, and region; the focus of issues; the types of data and impacts you expect to measure and the scope of regional interest, i.e., other publics, federal, state, and local agencies. The regional boundaries for different resources and data may or may not coincide. As an example, the area for collecting data about forest products may be a multi-county area. The data for recreation resources will probably be altogether different. Areas for different resources may overlap; however, they will probably not be identical. The physical resource inventories can be conducted on units which match physical characteristics and these units, when totaled, should match the regional boundaries which, in turn, reflect priorities, program problems, etc.

It should go without saying that we select inventory procedures which are appropriate to the unit being analyzed. The procedures chosen should, in essence, be responsive to purely technical considerations which hinge on the geographic scope of the inventory and analysis. Again, these procedures should be selected with an awareness of the importance of the issues,

problems extraneous to, as indicated by the levels of interest and implications of problem resolution. This means in areas where issues are non existent, resource values low, and problems are small (as determined by preplanning). The physical inventory should not be designed to collect intensive resource data on small units. You should tailor your physical inventory units to information needs. Perhaps, in this example situation, inventory units could be several thousand acres in size.

Lastly, in many instances, limitations on the amount and quantity of physical data readily available, or other constraints such as staff or money available, time constraints, etc., may mean that regional inventory procedures will have to be modified. In other words, selection of inventory procedures and data required must, in the end, weigh concerns for inventory vigor against cost and feasibility of a particular approach. When this becomes the case it is even more critical to know what data you need to make the management decisions. That is why good preplanning is essential in conducting integrated inventories. Without good initial planning you are likely to miss issues and badly needed data or collect data that because of generalness or detail is of little value.

BENEFITS

Integrated regional inventories are needed because resource values and ultimately the use conflicts which emerge affect agency programs, priorities and the publics. We should be better able to make informed decisions regarding these resources if we tailor our basic data gathering to the management policies we intend to carry out for these resources.

In this way integrated inventories, coordinated and well planned, can provide managers data to identify problems and issues either current or potential; provide a basis for developing good resource programs; provide a basis for feedback on resource trends; provide a basis for coordination with other federal and state resource management agencies; provide data for interim critical management; help set priorities on data needs and programs; provide a cost effective means to gather needed data without duplication and overlap; and provide a means to "look at" regional needs as opposed to local situations.

In summary, well-thought-out regional integrated inventories can provide needed data to help meet agency goals, objectives, issues and problems. However, they must have adequate preplanning, recognize agency goals and issues, and be coordinated with other federal, state, and local agencies to realize their full potential.

Integrating Broad-Based Forest Inventories with Management Inventories for Small Private Ownerships[1]

Carlton M. Newton[2]

Abstract.--A discussion of the need to and potential for, incorporating the results from broad-based forest inventories into the design and analysis of management inventories on small private forest holdings. All too often the two types of inventories are designed and conducted as totally separate efforts. Computer based information systems are considered necessary if broad-based information is to be made easily available to the landowner. Vermont is presented as a case in point.

INTRODUCTION

In some parts of the country, private forest ownerships of steadily decreasing acreages are becoming a major component of the forest economy. In the State of Vermont, 76 percent of the land area is considered forested (Kingsley, 1977). If corporate and organizational ownerships are excluded, it is found that 49 percent of the entire state is forest land that is owned by individuals, with an average size of less than 40 acres. A recent Forest Service study of Vermont's forest landowners (Kingsley and Birch, 1977) revealed that recreation, and providing a place of residence, were ownership objectives which were more important than timber production. In such a situation, providing inventory information on which management decisions will be based is a real challenge.

The purpose of this paper is to discuss the need to, and potential for, incorporating results from broad-based forest inventories into management inventories for small forest holdings. The State of Vermont is used as a case in point.

INVENTORY DEFINITIONS

A management inventory is assumed to be location specific, and providing information regarding the entire ownership. Particularly for small ownerships, say less than 100 acres, the information which is provided may be presented on a per stand or compartment basis. A broad-based inventory, on the other hand, is one which provides information on a regional basis, across many stand, cover type, ownership, and political boundaries. Broad-based inventory information is used frequently by governmental agencies, and the forest products industry, but only rarely by small private forest landowners.

With the passage of the Forest and Rangeland Resources Planning Act of 1974 (RPA), the Forest Service began extending their regional Forest Survey beyond timber, to include all of the renewable resources. As such, resurvey field instructions have been modified to include additional resource parameters that can be observed at the permanent sample ground plots (e.g. US Forest Service, 1977). As more multiple resource inventory data becomes available, the greater the potential for providing landowners with information which might be helpful in making their management decisions.

LAND OWNER INFORMATION NEEDS

If Vermont is any example, private landowners are interested in more than timber production. As land holding costs increase, ownerships seem to be subdivided, and/or transferred to more prosperous owners. As a result, management for timber production becomes more difficult due to the smaller size of the holding, or less critical to continued ownership due to the affluence of the owner. If timber production is abandoned voluntarily as an owner objective, it may well be replaced by management for wildlife, personal or commercial outdoor recreation, aesthetics, or residence protection.

With a shift in management direction comes a redefinition of information needs. In-place resource data is still needed, but now it covers a much wider spectrum. Cover type and timber volume data is supplemented

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[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, 8-12 January 1978.

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with inventories of soils, understory vegetation, wildlife, and water tables. Besides the need for inventory data, there is the need for predictive information. Just as timber inventory data may be used to predict probable yields, landowners are looking for predicted multiple resource consequences of their management actions.

The problem of course, is that small individual ownerships rarely, by themselves, justify the type of intensive information system that is desired. The School of Natural Resources at the University of Vermont is currently engaged in long term research which addresses the challenge of integrating an increasing diversity of ownership objectives with the wise use of forest resources.[1] A tenant of the project is that it is increasingly important that private ownership actively contribute to the supply of resources according to their capability. It is assumed that private forest resource owners need, and would use, technical multiple resource assistance in planning and implementing solid ecological and economic decisions. Therefore, a necessary component of the project is the development of an information system which not only provides for the efficient collection of multiple resource data, but also an evaluation of the probable consequences of management decisions on small private ownerships.

BROAD-BASED INVENTORY DATA

There is a wealth of meaningful broad-based inventory data that is potentially available to the private landowner. The private landowner in Vermont generally does not own and manage his land as his primary source of income. He is quite likely ignorant of both the management limitations and opportunities of his property. For example, an owner may be overly optomistic about the capability of his 40-acre parcel to generate a substantial long term annual income from the wood grown. On the other hand, he may be unaware of the land's excellent potential for grouse management, or that his property is used as an access route to an established deer yard. Broad-based inventories may provide him with location specific information, the vehicle for communicating applied research results, or the basis on which to design a management inventory.

Location Specific Information

Location specific information is often available if the landowner only knew where to go and what to look for. Much of the data is summarized on maps. Topographic, geological, and soil survey maps describe the land. Regional planning, and zoning maps delineate land use restrictions. Road locations, weight limitations, and road surface conditions may be found on transportation or highway maps. State and federal wildlife agencies frequently maintain maps locating deer yards, special hunting zones, stocked and unstocked fishing streams, as well as seasonal yields by area or body of water. Forest pest and disease outbreak and spread patterns are also stored in map form. Recreational data such as hiking, skiing, and snowmobile trail locations are available from many sources.

At first glance much of the information may be considered interesting, but hardly of much use to the small forest landowner. The impact of this information increases substantially when it is used as a vehicle for communicating applied research results.

Applied Research Results

The landowner may not know where to go to find out what tree species will grow well on his property, or what types of wildlife are frequently associated with the type of vegetation found on his land, or whether or not his timber stands are considered overstocked for optimum growth, or the recommended fish species for the stocking of his stream or pond, or what ground cover would be most suited to combat soil erosion. Information of this type can easily be reported in conjunction with the previously mentioned location specific maps.

Soil survey reports done by the USDA Soil Conservation Service are good examples of the use of broad-based surveys to communicate applied research results. A recent soils report for Vermont's Chittenden County (Allen, 1974) provides soils type maps for the entire county. For each of the defined soils types, associated information includes estimated average acre yields of principal crops for two levels of management; potential productivity classes for commercial timber; general estimates of erosion hazard levels, windthrow hazard levels, probable seedling mortality, limitations to conventional equipment use for timber management, anticipated rates of invasion by unwanted trees, shrubs, and vines when the canopy is opened; limitations for wildlife habitat and kinds of wildlife; soil engineering properties and recommendations; and suitability for community development and developed recreational uses.

While most soil surveys present only generalized statements of applied research results, this does not have to be the case.

[1]The Grafton Forest Resources Project funded by the Windham Foundation.

Refinements of the estimates can be made to keep pace with current research. A basic principle is that the ancillary information which accompanies a map should be strongly correlated with the mapped characteristics. The weaker the relationship, the more difficult it is to communicate research results that are applicable to a particular land parcel.

Observations from numerous broad-based inventories may be merged by sorting the observations from one survey according to the parameters of another. The Forest Survey may be combined with the Soil Survey by identifying the soil type for each forest measurement plot. Such post-stratification may result in some soil type strata having few if any plots. But for those soil types well represented, forest survey data may be summarized and reported according to soil type. An obvious difficulty of such an information system is the cost of updating, verifying, and sorting the pertinent information in a format that is conveniently available to the landowner.

Management Inventory Design

Broad-based inventory information will never replace the management inventory. They should not, however, be considered totally independent. The regionalized information can be of help in the design of a suitable and efficient management inventory.

Two classic questions which are asked when an inventory is designed are "what shall I measure" and "how many sample units should I select". The answer to the first ultimately rests with the landowner and his management objectives. Just as researchers should do a thorough literature review before embarking on new projects, so too should landowners check the currently available information before beginning the management inventory. Particularly where the inventory has multiple objectives, it is possible that some of the desired information is already available at an acceptable level of accuracy and precision. Common examples of this are found in the frequent use of USGS quadrangle sheets and aerial photos to depict the terrain and overstory forest cover types.

Broad-based inventory information could also be of use in addressing the question of sample size. The more known about the population in question, the more sampling designs available, and the more precisely an appropriate sample size can be estimated. Broad-based inventory information could quite easily provide the basis for stratification, estimates of variability for sample size calculations, and information on possible concomitant variables. The difficulty of course is in making all of this information available to the landowner.

INVENTORY INTEGRATION

What is the potential for combining broad-based inventories with management inventories, and making the results available to private individuals? By definition, the management inventory information is already available. Therefore, the question reduces to one which is largely related to regional information management. In my opinion, the keystone is computer technology. With mind-boggling advances in computer software as well as hardware technology, an exciting opportunity exists to influence the private forest landowner. Research efforts throughout the country are ongoing with the basic objective of developing multiple resource information systems which not only process, store, and retrieve inventory data, but also evaluate possible management alternatives.

Discussions of the various technical modeling philosophies have been presented (e.g. Bare and Book, 1974) and probably will continue to be for some time. Unfortunately many of the systems which I see being developed are oriented towards the management of large tracts of land. With small tract management as the basic justification, there appears to be three system characteristics which are desirable.

Polygon Data Storage

The broad-based inventory information could be stored according to a cell system, or a polygon system. Under the cell system, an entire region such as a state, would be divided into a collection of cells. Frequently these cells are of the same size and shape. Information pertaining to each cell is then stored as the characteristic of area. Updating is accomplished by changing the cell's associated information, not by changing the cell dimensions.

Polygon storage can be thought of as being based on cells which have no particular size or shape. Map data is stored in the computer with the aid of a digitizer which automatically encodes the boundary of a cell as a series of X-Y coordinates. Each polygon is entered and identified separately. Thus, a user could go back and locate a particular polygon anywhere in the system and review the listed information that is associated with it.

The cell system is very efficient relative to data storage and retrieval. Polygons on the other hand are very flexible in that they can

handle a wide variety of different data types. The traditional drawback of the polygon system has been that it is difficult and costly to update the file for changes in boundary location, or cell contents. Broad-based inventories, by their very nature, do not require frequent updating. And, since it would be difficult to construct an operationally efficient common cell size or shape to deal with private ownership boundaries, it seems that inventory integration would require the polygon approach.

Area Review

Assuming that the broad-based inventory information is stored according to the polygon approach, the system should be capable of accessing and recalling all the information associated with a user defined area. The landowner specifies the coordinates of his ownership, or more practically, an area enclosing the parcel. He should be able to receive a listing of all, or selected parts, of the data which are associated with this area. Without this feature, information which characterizes his ownership is linked to some predetermined cell dimensions and many of the advantages of polygon storage are compromised.

Data Processing and Prediction

The third requisite of the inventory integration effort is that it be easily accessible to the landowner. The basic objective of an inventory system is to provide an accurate storage, retrieval, and updating service. Operation of the system should require little more than a casual knowledge of data processing techniques. Furthermore, no knowledge of computer operation should be assumed. Output should be simply presented, self-explanatory, and available on screen or paper in tabular, graphic, or map form.

A highly desirable aspect of the system is that it be capable of processing typical management inventory data. After processing a landowner's inventory data, options should be available for the prediction of the consequences of contemplated management actions. Realistically, this feature could not be made so general as to handle any type of inventory design or management action.

The approach being taken of the University of Vermont is to limit the inventory and management actions to timber. Although private land managment objectives are quite variable, the most common basic component of management is the tree population. Furthermore, one way in which actions related to non-timber objectives can be meaningfully evaluated for private landowners is in terms of the probable income lost due to foregone timber management opportunities.

SUMMARY

In summary, conditions are such that more and more forested acreage is going to small private ownerships. With this transition, the management objectives tend to become increasingly variable. All too frequently these owners are unaware of the characteristics associated with their land, and thus may be ignorant of management opportunities, physical or legal limitations, and probable management consequences. The small private landowner does not have a staff of trained professionals at his disposal to inventory and evaluate his land from a multiple resource point of view. He has the need to rely more on broad-based inventory results than most other groups of forest land managers, but yet such data is generally unavailable in an easily understood format.

Primarily through the use of computer technology, broad-based inventory data could provide the landowner with an assortment of helpful location specific data, a means of reporting applied research results, and a basis on which management inventories could be planned, Providing such assistance to private landowners requires a general reorientation in the design of information storage and retrieval systems. The effect of integrating broad-based inventories with management inventories can be substantial. Unfortunately the objectives of the two types of inventories are often considered to be separate and rarely of importance to the small private landowner. The development of information systems should be oriented towards the private landowner, and federal, state, and university researchers should provide the necessary leadership.

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Integrated Resource Inventories of Industrial Forest Land[1]

Louis O. House IV[2]

Abstract.--The need for different kinds of integration of forest inventories is discussed in the context of the economic and social environment of industrial landowners.

INTRODUCTION

It becomes readily apparent when considering the need for integrated inventories of industrial forest lands, that there has yet to evolve a clear understanding of what is meant by integrated inventories. I propose, therefore, to begin by suggesting some possible meanings for the phrase, especially as it might apply in the industrial environment. I will then beg your indulgence while I make a few obvious, but often overlooked, observations about that industrial environment. Finally then, I will turn to the main purpose of this paper: to review specific needs of industrial forest landowners for integration of their inventories and suggest possible guidelines for accomplishing it.

INTEGRATION IN WHAT SENSE?

There are many ways in which the concept of integration may be applied to natural resource inventories. To provide a frame of reference for this discussion, I find it useful to divide them into two broad categories: preinventory integration and postinventory integration.

Preinventory integration consists of any kind of integration affecting the formulation of inventory objectives, the selection of sampling designs, the delineation of precision requirements, or the actual conduct of inventories. Examples of such integration would include:

- multiresource inventory objectives oriented toward general area descriptions as opposed to specific resource information requirements,
- coordination of data element selection between different information users,
- formulation of sampling designs capable of yielding multiresource data at varying precisions, and,
- development of measurement standards for different data elements.

By postinventory integration, I mean any type of coordination or processing systems affecting the use of inventory data. This obviously includes:

- data entry and validation,
- data organization and storage based on logical constructs other than those required for predescribed reports,
- data access, retrieval, and updating methods, and
- the application of derived information to policy formulation, operations decisions, and research.

THE INDUSTRIAL ENVIRONMENT

Before considering any specific needs industrial forest landowners might have for resource inventory integration along either of the lines just described, I believe it is necessary to review the rationale for industrial land ownership. Industrial land holdings represent a form of investment regardless of how or why they were initially acquired. As with most investments, they are expected to yield a reasonable return to the owners. Some companies generate

[1]Paper presented at Integrated Inventories of Renewable Natural Resources: A National Workshop, Tucson, Arizona, January 8-12, 1978.

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this return in the form of direct profits coming from the sale of commodities found on or in the land or through the collection of land use fees, while others use their natural resources to supply conversion and manufacturing facilities. Most large industrial landowners are vertically integrated and thus fall into the second category even though they might generate some direct returns from their land bases.

Great Northern Paper, a Company of GNN Corporation, is an example of the vertically integrated, industrial landowner, with major conversion and manufacturing facilities. In this environment, resource management is viewed as being ancillary to their manufacturing activities. This outlook is clearly evident in the opening of the Company's statement of forest management objectives:

> "The primary forest management objective of Great Northern Paper is to provide a sustained yield of forest products for the Company's manufacturing facilities in Maine. The development of the maximum yield of timber products and profits from the forest is a secondary major objective."[3]

This policy statement makes it clear that, unlike public land-managing agencies, Great Northern Paper has chosen to focus its limited manpower and financial resources on the timber fraction of its two million acre land base. This is an intentional decision based upon the Company's assessment of how it can generate the greatest return on its investments for its owners.

The needs are obvious, within this environment, for detailed inventories of the specific resources being utilized. Information about the location, volume, and condition of the timber resource is necessary to plan and control harvesting operations, to evaluate proposed capital expenditures for converting and manufacturing facilities, and to evaluate lands for acquisition, disposition, or exchange.

The preoccupation of industrial landowners with primary forest products, however, does not preclude them from recognizing other values associated with their land holdings. Indeed, Great Northern Paper's forest management policy statement goes on to state:

> "In the pursuit of its primary and secondary objectives, Great Northern Paper will seek to protect and maintain other valuable resources associated with its forest lands. These include the soil and water resources, fish and wildlife, and recreational and aesthetic resources."[4]

This innate concern shared by most land managers is being increasingly echoed by societal attitudes and governmental regulations. Recent efforts by many groups appear to be aimed at expanding the interpretation of public rights to private industrial lands. Increasing attention is being focused on the impact of forest management activities on these rights as well as their impact on all other aspects of the forest and associated environments.

Together, these factors suggest that there may be a need to expand the objectives of inventories of commercial forest land. This expansion would require describing, quantitatively and perhaps qualitatively, significant elements of the diverse resources associated with industrial forests.

INDUSTRIAL NEEDS FOR INTEGRATION

Thus far I have suggested that it might be useful to consider integration of preinventory activities separate from integration of postinventory uses of data. I have also discussed the industrial landowner's established need for additional information. In this, the concluding section, I will attempt to bring these two themes together by discussing the integration of inventories of industrial land holdings. I hope, in the process, to delineate some criteria useful for accomplishing the different kinds of integration.

It appears to me that there are three distinct areas of need for integration in industrial inventories in the preinventory sense. The first and most obvious need is for organizational integration. My experience suggests that most industrial landowners have recognized this need and integrated their inventory work into unified operations with centralized direction. This, of course, is usually a functional inventory, but there is no reason to expect that this will or should be changed as inventory objectives are broadened.

The development of consistent measurement standards is the second area where preinventory integration is necessary. I believe that industrial landowners should actively seek to participate with public agencies to standardize the methods for measuring different forest resources.

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[3]Forest Management Policies, Woodlands Department, Great Northern Paper, November 30, 1977.

[4]Ibid.

I mean this to include both the specific measurements to be made and the units in which they will be measured. The myriad of traditional units of measurement admittedly makes this a difficult task. The forthcoming conversion to metric units, however, provides a unique opportunity to clear this hurdle. The most obvious justification for private industry's involvement comes from the resulting ability to check for gross errors in their own work, and from the possibility of using data collected by public agencies to improve the precision and extend the scope of private surveys.

Preinventory integration of industrial inventories to include multiresource data is a third area that should be considered. I take multiresource inventory to mean an inventory designed to describe significant portions of the geology, soil, flora, and fauna of land units, as opposed to the more traditional single resource inventories. While the need for this kind of inventory in the industrial environment is not clear economically, the growing demands from external agents are forcing industrial landowners to consider a broader range of attributes of their land base.

As we move to expand the scope of industrial inventories, there are two criteria that I believe useful in determining which data elements should be included. Obviously, all marketable resources should be included. Marketable resources should include both commodities with established markets and those for which there is a reasonable probability of developing a market. Commercial tree species, identifiable mineral, and energy resources clearly fall within this category. Expanded resource inventories might also include such things as landforms and bodies of water with the potential for commercial recreation development.

The second criterion concerns the relationship of potential data elements to resources with existing commercial value; that is, those factors should also be included which influence a company's ability to extract and use commodities. Soil and moisture regimes are examples of such factors as they have significance in determining the current condition and future growth of timber stands, as well as presenting possible limitations in the harvesting methods and equipment that can be used.

This is not necessarily a clear criterion as there exists at least two different kinds of interrelationships between resources. From the commercial viewpoint there are the economic links between resources. These are the factors influencing how much of a commodity is available and the costs of extracting it. The other type of interrelationship involves changes, either temporary or permanent, that occur within one resource as a result of utilizing another. Obviously, the first type of interrelationship is of primary importance to the industrial landowner, while the second type is of increasing interest to regulatory agencies and the public in general.

Neither of these criteria is really new. They reflect the judgements already required to design traditional functionally oriented inventories. It is important to keep in mind that they remain valid for multiresource inventories. The process of integration does not, in itself, create needs to measure specific data elements.

Any distinction between organizations, be they public agencies or private industry, is mitigated when postinventory integration is considered. Here there is a clear need to integrate the storage, the retrieval, and most importantly, the use of all available and relevant inventory data. This is true even when preinventory integration, as I have defined it, is absent.

All of us working in this field have experienced the frustrations of knowing that existing information is not being utilized in the decision making processes. This occurs whenever decision makers are unaware of the existence of data, when it is too inaccessible, and whenever it is in a form that is incompatible with other information being used.

Postinventory integration, then, must address the problem of organizing data so that it can be accessed and used as needed. It appears to me that data bases, complete with data base management systems, are the most promising means to postinventory integration.

We at Great Northern Paper, like our counterparts with most other large industrial landowners, are in the process of reviewing and adapting the data base concept to our resource inventories. Despite considerable research and development that has already been carried out by universities and software firms in this area, it remains to be seen if they can economically meet the needs for postinventory integration of resource inventories.

If this prescription for integration of industrial inventories is less than clear, it is because each company has a unique land base, a particular set of conversion and manufacturing facilities, and its own policy for conducting its business. Within this varying environment, I hope I have suggested some common needs and strategies for integrating industrial inventories.

Methodologies for Designing Resource Inventories to Support Management Information Systems[1]

Dwight R. McCurdy and Charles C. Myers[2]

Abstract.--To design an integrated resource inventory to support land use allocation, the data needed to determine suitability of a tract for the selected uses must be stipulated. Several techniques for allocating priorities on these data for inclusion in the inventory are discussed.

The above title, by itself, is incomplete. To become relevant, the question must be answered, Methodologies for whom and for what? Primarily, the paper is written for natural resource managers and planners faced with the decision of land use allocation. In the past, much of the land uses have resulted from traditional use patterns, political opportunism, and manager bias. Today, with our multiplying demands and dwindling supplies, natural resource managers need a systematic, scientific manner of evaluating and implementing land use alternatives.

A model that is becoming popular in land use allocation entails the following steps.

Step 1

First, a list is assembled of all land uses which are (1) compatible with the agency's objectives or mission, (2) compatible with the land resources, and (3) have an expected demand not being met elsewhere. Land uses are defined to include activities, products, and services.

Step 2

Next, the suitability of the area to accommodate the selected land uses are analyzed. This suitability determination usually provides not only the amount of each use that can be allowed, but also the location (sites) at which the uses can occur.

More specifically, the suitability determination usually provides the following quantitative data: (1) Current capacity or production rate; (2) Planning period capability; and (3) Ultimate capability. These quantitative data many times are portrayed on overlays or maps.

For most land uses, capacity standards are generally developed. For example, a given site could have a capacity for 10, 50, 100, or 1000 picnickers, depending on the quality of experience desired. When more than one quality of experience is provided or product produced, each is generally considered a different land use. For example, family camping versus back country camping are considered different land uses.

Step 3

After learning which of the selected land uses might be allowed, the next step is to conduct a market analysis for each use to determine need. Need is defined as the deficit of demand after all supplies for a given land use have been exhausted in the land's market area for a given planning period. The market area encompasses the region (distance) surrounding the land from which people would normally take advantage of the use. The market area for each land use will generally be different.

Step 4

When planning future land use allocations (at first assuming unlimited financial and human resources), we are generally limited by either the "need" for our land use or by the land resources suitability. Therefore, the next task is to calculate the quantity

[1] Paper presented at the Integrated Inventories of Renewable Natural Resources National Workshop, Jan. 8-12, 1978, Tucson, Arizona.

[2] McCurdy is a professor and Myers is an assistant professor of forestry, Southern Illinois University, Carbondale.

(maximized output) of each land use that could be allowed.

Step 5

With limited resources, we know that the maximized output for all the land uses generally cannot be met and priorities must be established so that trade-off decisions can be made. Therefore, the next step is to choose a value system or criteria for establishing priorities between alternative land uses. In business, priorities between investment decisions are often based on the dollar return on investment - those investments with the largest returns being given highest priority. For public lands, several criteria have been used in the past such as maximization of present net worth.

Step 6

The trading-off of alternative land uses is accomplished using the value criterion selected. Before making the trade-offs, a functional analysis is often made to determine which uses are neutral, complimentary and competitive.

Obviously data are needed for each step in the land use allocation process. However, for this paper we will be concerned with only the natural resource data requirements for Step 2, land suitability determination for selected land uses.

When the natural resource data needs are classified for inventory purposes, it becomes obvious that some data are more important (by several criteria) than others. Similarly, it is reasonable to expect differences in the relative value or costs of data. All agencies are constrained by money, time, skilled personnel, equipment, and a host of other factors. Undoubtedly the most profound and interactive constraint is the size of the budget. Generally, there will not be adequate funds available to collect all of the desired data for suitability determination. Consequently, to make decisions most effectively, an agency must try to determine the relative value of data and then collect those data that are most valuable in terms of suitability determination, or those inputs that provide the greatest capabilities per dollar spent. Looking again at past management patterns, when conducting resource inventories we either took the shotgun approach or made a functional inventory. In addition, we were often somewhat traditional in the form the data were collected. As a result, much of the data were either of marginal usefulness or totally worthless.

Therefore, the methodology to be discussed may be useful in weighting (or ranking) the alternative data needs (kind, form) in land suitability determination so that the supporting integrated resource inventory will obtain the data of highest priority.

With the earlier assumption of limited administrative resources and an objective to determine the suitability of a given tract of land for selected uses, a first step in developing an integrated resource inventory would be to force the respective land specialists to develop suitability criteria. For example, to produce a given timber product, a set of specific site requirements would be needed. The criteria should stipulate the type and form of data needed. These data can then be weighted (or ranked) for priority on the basis of a value system.

Several potential methods exist for exploring the relative value of data needs. One technique which has been applied in similar valuation problems is the "subjective-ranking technique." The subjective-ranking technique requires that a team of representative land use specialists rank in order-of-importance the data needs used in determining suitability. An easy way to use this technique is to ask the question: "If you will agree that this list constitutes the data needs to determine suitability and you cannot afford to have all the items, which is the first, second, etc., that you would be willing to give up?" In this manner it is possible to rank the data, assigning a proportionate index of importance from 0 to 1.0 to each input in the group. By averaging the indices for a datum over all land uses, an index of importance can be obtained for a particular datum. Table 1 illustrates an example of obtaining subjective values for a few input datum. The results indicate that datum number 51 is more valuable in suitability determination than item number 9, however, the index does not indicate how much more important, only that it is relatively more important.

There are several deficiencies inherent in the subjective-ranking approach. One is simply the mechanics of getting people to provide the time necessary to rank the datum. A second and more serious problem exists in being able to get consistent ranking of inputs. The problem is partially alleviated by using group consensus in ranking or averaging entries from a group.

Table 1. Illustration of the subjective-ranking technique for determining the relative value of information items.

Datum Ident. Number	Land Use A	B	C	Subjective Value Index
9	0.3*	0.1	0.2	0.2
51	0.5	0.3	0.4	0.4
68	0.6	0.1	-**	0.3
.	etc.	etc.	etc.	
.				
.				

*Numbers in the body of the table indicate the value index for that input in that particular decision.

**A blank indicates item #68 was not needed for land use C.

Another technique potentially more powerful than the subjective-ranking approach is to allow quantitative values to be assigned to datum. This technique explores the relationships between land uses and datum frequencies through a sorted matrix. Table 2 illustrates such a hypothetical matrix, in which the information items are listed (decreasing top to bottom) by the number of datum required.

Table 2. A hypothetical sorted decision matrix demonstrating frequency of use of datum in suitability determination. Land uses are listed in order of decreasing number of datum required and datum by decreasing frequency of use.

Land Use	Datum 46	28	51	43	75	Total
B	1	1	1	1	1	63
E	1	1	1	1	0	63
A	1	1	1	0	1	61
C	1	1	0	0	0	.
D	1	0	0	0	0	.
.						
.						
.						
Total	119 . . .					
%	97.54 . . .					

A number of potential analyses can be made possible through the decision matrix. In one of the simplest, the matrix is inspected for the frequency of use of information items in suitability determination. A preliminary simplifying assumption for analysis is made that all datum have equal cost and all land uses are of equal importance. A first, and conceptually the most simple valuation can be made assuming that the higher the frequency of use, the higher the value of the datum. This value relationship can be expressed symbolically as: $V(I_j) = \Sigma D_i$ where the value of the jth datum (I_j) is equal to the sum of the number of land uses criterion in which the jth datum is required.

where i = the ith land use

D = a counter

and $D = \begin{array}{l} 1.0 \text{ if datum j is required} \\ 0.0 \text{ if datum j is not required} \end{array}$

For example, the rows at the bottom of Table 2 indicate that item number 46 is needed in 119 land uses criterion or 97.5% of the land uses. Another way this statistic could be interpreted is that the probability that datum number 46 will be used in suitability determination in the 122 land uses is 0.9754, where certainty equals 1.0. The major weakness in the example just discussed is the over-restrictive assumptions that datum have equal costs and that land uses are equally important.

It is at this point that the previously described classification begins to allow more precise evaluation of datum needs. Within the classification system, the category Magnitude of Importance provides another index of importance for each decision. The previously described "number of datum," and thus complexity, is another such index. Using one of the above indices of suitability determination importance allows the previous value expression to be altered to include a weighting factor. The symbolic equation thus becomes $V(I_j) = \Sigma w_i D_i$, where w_i = a weighting factor reflecting the relative importance of the ith land use. Removing the assumption that all land uses are of equal importance allows a more realistic evaluation of an input. For example, if the 119 land uses in which datum number 46 is used were searched for those with a Large Magnitude of Importance, it is possible that none of the 119 land uses in which item number 46 is used has a Large Importance. Consequently, in terms of making decisions of Large Importance item number 46 would be insignificant in overall suitability determination.

A second way to use the decision matrix is in an analysis of the grouping of data.

Some relationship may exist between a group of data that causes them to be used together in a number of land use criterion. If such relationships exist, they need to be considered in selecting data to be included in the integrated resource inventory. If items show strong grouping tendencies, the removal of certain items could reduce the effectiveness of the remaining items for suitability determination.

A third way to use the decision matrix is to determine how many (or which) datum are needed to make some portion (e.g., 50%) of the suitability determination. The classification system can provide the criteria for picking out which 50% of the land uses are desired. Another criterion might be the selection of the 50% of the land uses that required the most inputs. Assuming that the number of datum required to determine suitability is an index to the complexity of the criterion. This analysis is approached by adding datum into a group (called a solution) until enough data are obtained to make 50% of the land use suitability determination. Obviously the number of datum required to make 50% of the suitability determination depends on the order in which the datum are brought into the solution matrix. The various orders can then be compared on the basis of information efficiency and cost per unit of information.

A final technique that can be used to explore the relative value of data needs make use of both the solution matrix and its associated frequencies of use, numbers of datum, etc., and some of the subjective value techniques. This analysis involved determining a RIP (resource inventory priority) for each land use based on the characteristics of each land use suitability criterion. In consultation with the representative land use specialists, a value can be developed for each category within each level of the data classification system. Each category is assigned a numerical value between 0 and 10 that indicated its priority for the collection of data for an integrated resource inventory. The higher the value the greater the priority for collecting datum for suitability. The values within a level are assumed to be cardinal values and, therefore, are additive within a level. For example as shown in Table 3, under Capability: a value of 8 indicates that this is a high priority category and that it is twice the priority of 4.

Table 3. Resource Inventory Priority (RIP) values assigned data classifications categories for land use suitability determination.

Classification[1/]	Categories[1/]	Value[1/]
Land Use, Demand (Need) - Market Area	Large	10
	Medium	6
	Limited	2
Land Use, Capability - Inventory Tract	Large	8
	Medium	6
	Small	4
Land Use Priority - Relative to Agency Mission	Highest	10
	Average	6
	Lowest	2
Importance to Suitability Information	Critical (Primary)	10
	Necessary (Primary)	8
	Helpful (Primary)	4
	Helpful (Secondary)	2
Frequency of Use	All land uses	10
	Several land uses	8
		6
	Few land uses	4
	One land use	2
Overall Usefulness - Beyond Suitability Determination	Unlimited-General Use	10
	Some General Use	8
	Limited General Use	6
	Suitability Determination Only	4
Data Availability	Available, Desired Form, Central Location	10
	Available, Desired Form, Scattered	8
	Available, Not in Desired Form, Central Location	6
	Available, Not in Desired Form, Scattered	5
	Not Available, Will Require Limited Field Work	4
	Not Available, Will Require Extensive Field Work	2
Collection Cost	Low	10
	Average	6
	High	2

1/ The classifications, categories and values would vary depending on the objectives and constraints of the resource inventory.

The assumption of cardinal values is necessary to allow the calculation of the RIP. It seems to be a reasonable assumption if a single decision maker provides the values, and if he recognizes the assumption of cardinality when he assigns the values. The values are additive between levels because they are assumed independent with respect to the value scheme.

Each decision has a RIP that is equal to the sum of the category values for that decision. The calculation for the RIP of the ith land use (RIP_i) is shown symbolically as:

$$RIP_i = r_{1m} + r_{2m} + \ldots + r_{9m}$$

$RIP_i = \Sigma\, r_{km}$ where m is a category within level k

The solution criterion is to enter the datum associated with the maximum RIP/input, or symbolically, $MAX{:}RIP_i/n_i$, where n_i is the number of new datum required to make the ith land use suitability determination. The magnitude of the RIP is assumed to be an index of importance of the land use, at least in terms of collecting information for suitability determination.

The above classification and weighting techniques are of broader value than determining what data are to be obtained in an integrated resource inventory. For example, agencies could use the techniques in evaluating what information inputs should be included in its Management Information System. To determine the appropriate inputs for an efficient Management Information System, it is necessary to identify the decisions that will be made. Among the requirements to design such a system include: (1) basic goals and objectives, (2) decisions to be made to achieve the goals, (3) processes by which the decisions should be made, and (4) information needed.

Summary

To design an efficient integrated resource inventory to support land use allocation, the exact data needs to determine suitability of tracts for the selected land uses must be first stipulated. Then because of limitations on the amount of data that can be collected, a next step would be to allocate priorities on the data for inclusion in the inventory. Several techniques for systematically obtaining these datum priorities were discussed in the paper.

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~~Panel IV~~ Land Classification Systems: Moderator's Comments

Richard S. Driscoll[1]

Unified planning and decision-making for natural resources requires the development of decision rules for securing and manipulating data and information for the decision-making process. Decisions on management of natural resources require an inventory of those resources to determine what they are, where they are, and how much there is. These resources--vegetation, soils, and water--exist naturally as continua. However, it is impossible to deal with them as continua since all that is presented is a complex array of data that is extremely difficult to interpret for management alternatives, decisions, and effects. Therefore, the continua must be segregated into groups of similar population units that are hierarchical from general to specific and specific to general.

Classifications are contrivances made by people to suit their purposes. They are not in themselves truths that can be discovered. There is no true classification--a perfect one that would have no drawbacks for the intended purpose. Any classification of natural resources must be viewed as a dynamic system that can be modified as basic knowledge of the resources and their characteristics is increased.

Land classification serves to organize knowledge and simplify complex interrelationships to identify land areas with similar properties. It provides structure for aggregating large amounts of information about land resources resulting from surveys and inventories. It increases the capability to generalize or specialize, extrapolate research results, transfer management experience, apply management practices, and evaluate management alternatives.

Many classifications of renewable resources are available and possible. They are either natural or technical. Natural systems are based on primary characteristics and character states of the objects classified. Examples of natural classifications are plant and animal species, soil series, plant communities based on kinds and amounts of individual species of the community, a kind of landform based on structural characteristics, or a water body based on physical and chemical properties.

Technical classifications are usually groupings within properly defined natural classifications for technical purposes or uses. For example, certain vegetation classes can be grouped into suitable or unsuitable range for livestock grazing or commercial and non-commercial forest for timber production. These kinds of classifications are usually driven by socio-economic demands and are generally transient. For example, the definition of commercial forest or suitable range could change, depending on economic demands for wood products and red meat production.

The most feasible kind of classification to establish compatibility for unified planning and decision-making is a natural system based on primary properties. The classification must be consistently hierarchical so that resource data for project, regional, or national planning can be consistently aggregated or disaggregated. For example, if a decision is made to increase supplies of a renewable resource, the classification system--with its adjunct data--must identify where efficient and effective programs and management can be applied to achieve the increases.

Other requirements of the classification system are:

1) Objectivity: The classification must be as objective as possible to adequately define the land classes in terms of inherent biological potential for resource production. Within this framework, it is necessary to describe and define the present situation to define opportunities and problems for management alternatives.

2) Relative Permanence: The basic attributes of the classification system should retain a relatively high degree of permanence. It is understood that some elements of the system, for example vegetation and soil, change as a result of resource management practices. However, some diagnostic characteristics remain relatively permanent and the class orders of the classification can be inferred by induction or deduction. Other elements, such as land surface configuration and general climate, remain quite permanent in the absence of catastrophic events such as landshifts, landslides, or other cataclysmic events.

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3) <u>Perceivability</u>: The classes and class categories can be seen on the ground and their attributes are observable and measurable. If the units of the classification system are not observable or their characteristics are not quantifiable, compatibility for resource inventories and management planning would be difficult, if not hopeless.

The following papers present some classification schemes currently in use or under development in the United States and Canada. The basic premise of the classifications presented by Buttery, Gimbarzevsky, Wiken, and Montanari and Wilen is definition of land units through natural properties. Those presented by Witmer and Ellis are examples of classifications that use remote sensing as a primary data source.

Modified Ecoclass — A Forest Service Method for Classifying Ecosystems[1]

Robert F. Buttery[2]

Abstract.--Modified ECOCLASS, a hierarchical, four-system method for classifying terrestrial and aquatic ecosystems, is a modification of the ECOCLASS method described in 1973. Modifications include the addition of a landform system to the three existing systems of vegetation, soil and aquatic, and improvements in each of these systems. The method provides flexibility in establishing a framework for use by land managers in securing integrated resource information for management decisions.

INTRODUCTION

In a 1971 report (Cliff 1971), the Chief of the Forest Service stated one of the major specific problems in management of the National Forest System as follows:

> "To develop and put into effect an adequate system to classify major forest types into suitable ecological subdivisions as a basis for improved forest description and management in coordination with range, wildlife habitat, and other resources."

He subsequently established an interdisciplinary task force to establish a classification system for the Pacific Northwest and provided the following guidelines:

1. The purpose is to provide a unifying framework for the various functional interests within which research and management can be planned and executed.
2. The classification should be hierarchical so it can be used at all organizational levels of planning.
3. The lowest level of the hierarchy should consist of perceivable units of the landscape, homogeneous in climax vegetation and in form and structure of the land.
4. The classification should be developed upon existing knowledge.

Using these guidelines, the task force developed a method of classification termed ECOCLASS, which is an acronym for ecosystem classification. ECOCLASS is a method, not a complete classification but provides a unifying framework for completing the classification.

THE ECOCLASS METHOD

ECOCLASS (U.S. Forest Service 1973) links Terrestrial Ecosystems and Aquatic Ecosystems. To describe Terrestrial Ecosystems, both vegetation and land characteristics are needed. Aquatic Ecosystems, which are portions of land covered with water all or most of the year, require descriptions of both aquatic characteristics and influencing terrestrial characteristics. ECOCLASS is used to link these ecosystems through the common bond of the Land System. Figure 1 shows the outline of the Vegetation, Land and Aquatic Systems and their possible linkages.

Levels within each System are designed for grouping closely related units of the next lower level. For example, several closely related Landunits are grouped into a specific Landtype; several closely related Landtypes are grouped into a Landtype Association, etc. The land manager can choose whatever level of detail from each System that he requires for his particular need.

In Figure 1, dashed lines connecting different levels of the Vegetation, Land and Aquatic Systems show possible combinations between levels of each System. Linkages made between the Vegetation and Land Systems to describe Terrestrial Ecosystems are termed Ecological Land Units (ELU's). Linkages between the Aquatic and Land Systems are termed Ecological

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[1] Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.

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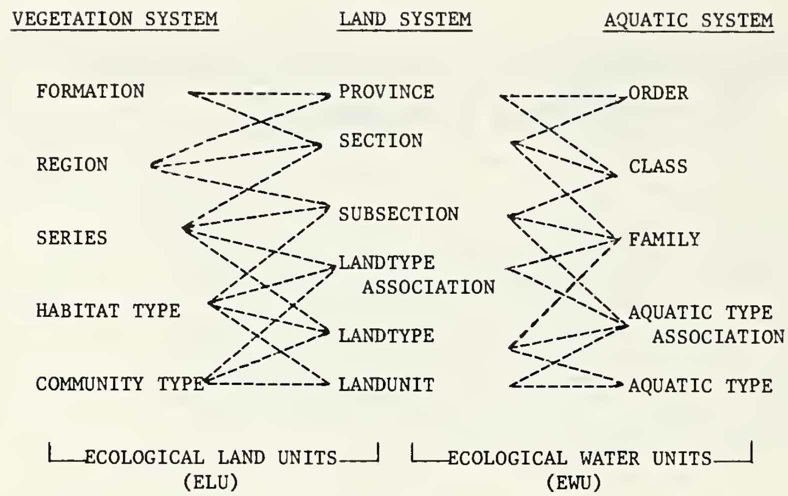

Figure 1.--Basic systems of the ECOCLASS method, showing the hierarchical classifications and possible combinations. Ecological Land Units comprise linkages between the Vegetation and Land Systems. Ecological Water Units are the linkages between the Aquatic and Land Systems.

Water Units (EWU's). ECOCLASS is not restricted to combinations of equivalent levels of each System, thus it is flexible. The method can accommodate and integrate data at any level for a wide variety of land management needs.

The Vegetation System

The Vegetation System is founded upon the belief that plant communities are meaningful integrators of interacting environmental factors (soils, landform, and climate). Levels of the system are named for their dominant species or kinds of plants as follows:

NAME	DEFINITION AND EXAMPLE
Community Type (C.T.)	Collective term for those areas of land supporting the same type of stable plant community (Cheatgrass-Sandberg Bluegrass C.T.). Some are equivalent to a Habitat Type whereas others are a subdivision of a Habitat Type to recognize dominant subclimax stages of succession.
Habitat Type (H.T.)	Collective term for those areas capable of supporting the same climax plant associations (Bluebunch Wheatgrass-Sandberg Bluegrass H.T.).
Series	Groups of Habitat Types having a common climax dominant species (Bluebunch Wheatgrass Series).
Region	Groups of Series with similar physiognomy and climatic controls (Montane Grassland Region).
Formation	Groups of Regions with similar physiognomy (Grassland Formation).

The Land System

The Land System is founded upon the fact that land areas result from specific combinations of soils, geology, land shape and climate. Levels of the system are as follows:

NAME	DEFINITION AND EXAMPLE
Landunit	The lowest unit of the system composed of closely related sites having uniform land shape (Landunit 224--soil from volcanic ash over stoney clay--Tolo Series--on a toe-slope of 10 to 20 percent facing south).
Landtype	Groups of Landunits having similar land shape (Landtype 31--deep, medium textured cold soils on dissected mountain slopes).
Landtype Association	Landtypes grouped according to their association with each other (Dissected Plateau).

Subsection	Groups of Landtype Associations with similar geologic history and physiognomy (Alpine Glaciated Lands).
Section	A specific land area with characteristic topographic, geologic and hydrologic properties in which any kind of Landunit, Landtype, Landtype Association or Subsection may fall (Idaho Batholith).
Province	A major land area made up of several Sections (Basin and Range).

The Aquatic System

The Aquatic System is based on the belief that waters of similar characteristics have similar capability to produce goods and services. Since land and vegetation greatly influence water, their characteristics are involved in describing aquatic units, although lines will be drawn around only those parts of the landscape covered with water all or most of the year. Because there is no generally accepted aquatic classification, system, the following is proposed:

NAME	DEFINITION AND EXAMPLE
Aquatic Type	A relatively homogeneous stream, lake, marsh, or estuary. Where the unit under consideration is diverse and large, it may be subdivided into smaller manageable units such as a reach of stream, a part of a lake, or marsh, etc. (Steep, headwaters stream).
Aquatic Type Association	Aquatic Types grouped according to their association with each other, usually on a drainage basis (Dissected Mountain Stream).
Aquatic Family	Aquatic Type Associations grouped largely by temperature (Cold Streams, Lowland Lakes).
Aquatic Class	Grouping of Families based primarily on their physical character (Streams, Lakes, Marshes).
Aquatic Order	Groups of Classes based primarily on salinity (Fresh-water, Inland Salt Lakes, Oceans).

As was recognized by the ECOCLASS task force, ECOCLASS, as the first step in formulating a method of ecosystem classification, has several weaknesses which hopefully can be strengthened over time as new information becomes available.

In 1975, to help overcome these weaknesses, the Regional Foresters of the Rocky Mountain and the Southwestern Regions and the Director of the Rocky Mountain Forest and Range Experiment Station established an ad hoc committee to develop a method of classifying ecosystems that would be compatible with the ECOCLASS method and be amenable to inventory mapping with aerial photographs. The committee, with the help of several specialists from both Regions and the Station, developed a method, termed Modified ECOCLASS, which is presented as a second step toward a completely useable method of classification for use at all levels of land management planning.

THE MODIFIED ECOCLASS METHOD

Although ECOCLASS presents an acceptably sound, generalized concept of a method of classifying ecosystems, it was determined by the committee that none of the component systems and the hierarchy developed under each were entirely pure in the sense of relating to a vegetation system, a land system, or an aquatic system. At various levels in the hierarchies, some categories were hybrids representing integrated classes either within or between the systems.

Figure 2 shows the hierarchical systems of Modified ECOCLASS (U.S. Forest Service 1977). The following discussion explains the reasons for modifications within each ECOCLASS System.

The Vegetation System of ECOCLASS includes "Habitat Type" as one of the lower level categories of that system. This is a deviation from the original ecological concept of "Habitat Type" and infers that all the resource examiner needs to do is evaluate vegetation to arrive at that level in the vegetation system. Consequently, there is severe misconception of the concept of "Habitat Type" and the following is presented to establish a common understanding between the Regions, the Station and others doing natural resources inventories as to the definition of a "Habitat Type:"

> "In the interest of clarity, it is desirable to make a distinction between vegetation and the area it occupies. The collective area which one Plant Association occupies or will come to occupy as succession advances is called a Habitat Type. Considerable variation of intrinsic factors may be encompassed but the ecologic sums of the different sets of conditions are essentially equivalent with respect to the nature of the climax. Each time the forest is destroyed, as by fire or logging, plant succession leading toward the same climax

VEGETATION SYSTEM	LANDFORM SYSTEM	SOIL SYSTEM	AQUATIC SYSTEM
PLANT FORMATION	REALM	ORDER LEVEL 7	ORDER
	MAJOR DIVISION	SUBORDER LEVEL 6	CLASS
	PROVINCE	GREAT GROUP LEVEL 5	
PLANT REGION	SECTION		
	REGION	SUB-GROUP LEVEL 4	
	DISTRICT		FAMILY
	AREA	FAMILY LEVEL 3	
	ZONE		
PLANT SERIES			
	LOCALE		
		SERIES LEVEL 2	AQUATIC TYPE ASSOCIATION
	COMPARTMENT		
PLANT ASSOCIATION	FEATURE	TYPE LEVEL 1	AQUATIC TYPE

ECOLOGICAL LAND UNITS (ELU)

ECOLOGICAL WATER UNITS (EWU)

Figure 2.--Basic systems of the Modified ECOCLASS method, showing the hierarchical classifications. Ecological Land Units comprise linkages between the Vegetation, Landform and Soil Systems.

Ecological Water Units are the linkages between the Aquatic, Landform and Soil Systems.

association is initiated once more because the fundamental characters of the habitat type are not permanently affected by disturbance." (Daubenmire 1952).

Thus, the Habitat Type is the kind of habitat which a Plant Association occupies or will occupy as succession advances following disturbance. Nomenclature for this unit of land has adopted the use of plant names because the plants are usually the most obvious evidences of the category, are easily seen, and this kind of nomenclature forms a means of communication among resource workers. This is probably the reason workers have come to associate Habitat Type only with vegetation. However, the discovery, definition and description of the entities involves examining both the biotic and abiotic features of the landscape. Consequently, Habitat Type has been removed from the Vegetation System hierarchy as defined by ECOCLASS and is subsequently referred to as the basic or fundamental Ecological Land Unit, the combined result of the biotic and abiotic environment representing the unit of land which will likely respond similarly to specific management strategies. It must not be construed, however, that a Habitat Type is a kind of vegetation association aligned with a specific kind of taxonomic soil and landform unit.

Compensating and limiting factors, not completely understood, play important roles in the development and distribution of vegetation associations. Consequently, extreme caution must be exercised in determining Habitat Types since frequently a vegetation association occurs on one or more soil taxonomic units and a soil taxonomic unit may support more than one vegetation association.

Community Type of ECOCLASS has been deleted from the vegetation hierarchy because it provides little inference of potential plant community development. However, there may be instances when plant community systems appear stable, but are not climax, and there is little or no evidence of change toward apparent climax. In these instances, they may be classified on the basis of existing vegetation but should be considered only as a descriptor of the present situation and not a level of the vegetation system hierarchy. These kinds of communities do need to be mapped and described for land base accounting and will be included in the hierarchy when it is learned where they belong.

In the ECOCLASS Land System, the higher levels of the classification, to the Landtype Association, used landforms to classify the units. However, at the Landtype level in the Land System hierarchy, kinds of soils are inserted into the sytem which provided a confounding element into the classification process. The Landunit simply defines a kind of soil. Thus, there is a double classification procedure melded into a single hierarchy which results in a hybrid system. A principal criterion for any hierarchial classification scheme is that all characters and character states used for the process must carry through the system.

Modified ECOCLASS, subsequently presented, separates the ECOCLASS Land System into two classification systems, Landform and Soils. Although this procedure identifies an additional classification hierarchy, it will provide the user of the method and the user of the data from the method the opportunity to integrate to any level of basic resource information rather than dealing with mixed systems.

The Aquatic System of ECOCLASS is based on the fact that waters of similar characteristics have similar capability to produce goods and services. The system as developed deviated from the classical hydrologic approach of describing and mapping water bodies as a part of a basic cartographic information system. It was stated in ECOCLASS that the proposed method for the Aquatic System needed validation by review and experience, but this was never done, except by this committee.

Serious review by the hydrologists and fisheries biologists from both Regions indicated some shortcomings of the ECOCLASS Aquatic System classification scheme. These shortcomings are primarily related to the lack of sufficient descriptive material for use as guides in classifying an aquatic unit into one of the categorical levels. Therefore, another hierarchial Aquatic System was developed and is presented herein.

It must be understood that the present committee is not advocating either system for immediate operational use. The fact remains that the ECOCLASS Task Force searched the world's literature for a method for classifying Aquatic Systems and found none totally suitable that included physical, chemical, and biological properties. Both systems need serious review and testing to determine an operationally acceptable Aquatic System Classification.

Combining various levels of the Vegetation, Landform and Soil systems and the information used to derive them will result in the classification of terrestrial ecosystems which will be called Ecological Land Units (ELU's). Combining levels of the Aquatic, Landform, Soil systems and the information used to derive them, will result in the classification of aquatic ecosystems which will be called Ecological Water Units (EWU's).

In classifying ELU's, boundaries will be dictated by changes in vegetation, landform or soils at the respective levels selected. In classifying EWU's, boundaries between EWU's and ELU's will be dictated by the normal high waterline of lakes and streams. In areas where the normal high waterline is not apparent (very wet meadows, marshes, seasonal stream channels, etc.), judgment based on the individual site characteristics must be used in establishing boundaries.

The term Habitat Type will be used only to designate ELU's and EWU's classified at the lowest level of the hierarchies. As previously stated, however, caution is required to avoid aligning taxonomic Plant Associations, Landform Features, Soil Types, or Aquatic Types on a 1 to 1 basis due to compensating and limiting environmental factors.

Modified ECOCLASS is intended, as was ECOCLASS, to be a method for classifying ecosystems to provide a framework for use by the land manager in securing resource information for management decisions. It provides the manager the option of choosing a level of classification within each of the Systems (Vegetation, Landform, Soils, and Aquatic) to be used in gathering the information required for specific resource planning purposes. Consequently, the method is flexible. Information concerning resource capabilities, limitations, and responses, associated with each level, becomes progressively diluted as one proceeds to higher levels of the

hierarchy, but the information associated with each progressively lower level will include that from the higher levels. The lowest level classification units are well suited for detailed project planning. The higher levels are best suited for Regional and National planning. Within the hierarchy, the land manager can choose the appropriate level or combination of levels for each type of planning problem.

The Vegetation System

The following definitions and criteria are presented to provide information for the Vegetation Classification system for both Regions and the Rocky Mountain Station. These are not necessarily new terms or concepts but adhere as closely as possible to the ecological literature. The definitions and criteria are ordered for the highest to lowest levels.

Plant Formation: The Plant Formation is the highest level of vegetation classification which is primarily controlled by major climatic relations. Each Formation is a complex of the next lower level of classification, the Region. Examples of Formations are: Coniferous Forest, Deciduous Forest, Shrubland, Grassland, and Alpine. The major criteria for discrimination between the Formations in their zones of transition are based on plant canopy cover of the overstory species of the associated formations. This level of discrimination is set at 15 percent of canopy cover of the trees. For example, in the transition between a Coniferous Forest Formation and a Grassland Formation, if tree canopy cover exceeds 15 percent, the area will be classed as Coniferous Forest. In the case of discrimination between Coniferous and Deciduous Forest Formations, the classification will be based on dominance of tree cover.

Plant Region: Every Plant Formation consists of two or more major subdivisions known as Plant Regions. These are plant communities associated regionally to constitute the Plant Formation. A Plant Region is similar throughout its extent in physiognomy or outward appearance, in its ecological structure and its general floristic composition. This subdivision of the classification is generally controlled by regional climate. For example, the gradation of grasslands from the eastern slope of the Rocky Mountains to the Deciduous Forest to the east include the Central Grassland Region and the Eastern Grassland Region. In the mountains, there is the Montane Grassland Region. An example of a forest Plant Region is the Temperate Mesophytic Forest Region.

Classification criteria for discrimination among Plant Regions are similar to those used at the Plant Formation level. Within a Plant Formation, the Regional discriminations will be based on simple dominance of the highest plant life forms. If there are inclusions of Plant Regions within Plant Regions, the classification criteria for segregating Plant Formations will be used.

Plant Series: Every Plant Region consists of two or more subdivisions known as Plant Series. These are Plant communties which have specificity of physiognomy of their ecological structure. Generally, this level of the classification scheme is characterized by one or two common climax dominant species. Examples of vegetation classification to the Plant Series level include the Ponderosa Pine Forest, the Englemann Spruce/Sub-Alpine Fir Forest, Great Basin Sagebrush, Grama/Buffalograss, and Grama-Galleta Steppe. Within a Plant Series, there are groups of Plant Associations.

Classification criteria for discrimination among Plant Series are usually based on dominance of one or two plant species. There may be instances, such as in the Southwest Mixed Conifer Unit, where classification may be made on the basis of multiple species dominance. The dominance criteria are usually based on highest structural life form of the plant species present. Frequently, there may be inclusions of Plant Series within Plant Series. When this occurs, the criteria used for delineations will be the same as those used at the Plant Formation level.

Plant Association: Every Plant Series consists of two or more subdivisions known as Plant Associations. A Plant Association is a grouping of plants that have reached dynamic equilibrium with the local environmental conditions and is equivalent to climax. On the site, there is no evidence of replacement by other dominant plant species and there is no evidence of serious disturbance. The areas located, defined, or described may frequently represent seral stages of the Plant Association brought about by man disturbances, or catastrophic events such as insect, disease, or fire and may be termed Associes which are indicative of seral conditions. In such cases, characteristics of the abiotic environment, i.e., slopes, aspect, or some soil characteristics, may need to be relied upon for tentative characterization and classification to a particular Plant Association. Although not a permanent part of the vegetation classification, Phase, a plant grouping resulting from site-differentiated variations within a Plant Association and not time-differentiated occurrences, should be identified on areas where the plant community differs somewhat from the Plant Association. The Phase is an assigned part of the Association and may be integrated into the Association with time. Some examples of Plant Associations are: Ponderosa Pine-Arizona Fescue-Mountain Muhly, Big Sagebrush-Thurber Fescue, Blue Grama-Western Wheatgrass,

and Kobresia-Tufted Hairgrass.

An example of an Associes is the Blue Grama-Little Bluestem Associes of the Ponderosa Pine-Arizona Fescue-Mountain Muhly Plant Association. An example of a Phase is the Arizona Fescue Phase of the Ponderosa Pine-Arizona Fescue-Mountain Muhly Association.

The criteria for classification to the Plant Association level is normally based on the climax species dominant within the major structured life forms of the community. However, total floristics of the community must be examined in relation to relative abundance of all species and the classification based on those species which comprise the major portion of the vegetation in the area. In the forested communities, there are instances where structure of the community is expressed in two or more layers, such as a tree overstory, a shrub understory and a herbaceous layer under the shrubs. In these situations, the classification of the Plant Association would be based on the dominant species in each layer. Frequently, in herbaceous communities, there may be species codominance in which case the classification is based on them. It must be recognized that all species within the community must be examined in relation to each other to provide final criteria for the classification process.

In the classification of the Plant Associations, or the assignment of a community to an Association, it is not always possible to locate relatively nondisturbed situations that contain climax vegetation. In these cases, nearby sites with similar abiotic characteristics should be examined to aid in assignment of the specific location to an Association or to develop a preliminary interpretive Association.

The primary purpose of providing the foregoing definitions and criteria for vegetation classification is to establish a common foundation between the Rocky Mountain and Southwestern Regions, the Rocky Mountain Forest and Range Experiment Station, and other Forest Service Regions, which will have synonymous effects for basic resource inventory, evaluation and assessments. The ecological concepts of classification to the Plant Formation and Plant Region levels are well established. At the Plant Series level, there are some differing opinions about the classification of some units to climax situations. Two classic examples are the Lodgepole Pine and Aspen Forests. In some cases, these Forests do, in fact, represent seral stages to some other obvious forest community. In other cases, these Forests present evidence that they are, in fact, climax forest units, and must be classified as such. The decision on how to classify such units must be determined through detailed on-site examination.

The Rocky Mountains present very complex changes in local environments due to rapid changes in elevation and complex dissection patterns. As a result, the vegetation patterns at all levels of the hierarchy are not always continuous nor are they always present. Local variations in topography as they affect the effective precipitation and temperature regimes must always be carefully considered in establishing the classifications. The general classifications to the Formation and Region levels are quite well established and can be rectified by utilizing existing vegetation maps. Classification to the Plant Association level must be the primary future emphasis.

The Landform System

Two main approaches have been used in developing landform classification systems: (1) morphometric and, (2) genetic or geomorphic. Morphometric classification is a simple classification of topography. Geomorphic or genetic classification brings together lithology, history and processes, and their interactions, which are responsible for the landform's existence. For land management planning, landform classification by the geomorphic approach is better since the ultimate purpose is to be able to predict how a landform will react to a specific action, and in order to do this, knowledge of how lithology, history and process have influenced the landform is required. Such a classification was developed by Nevin M. Fenneman (Fenneman 1928), but was not formally extended below the fourth order, or Section level. The Modified ECOCLASS system is an expansion of Fenneman's system and follows closely one presented by Fairbridge (1968). It is a preliminary attempt to produce a useable system, and will necessarily be modified and improved as new knowledge and experience is gained. Figure 3 shows the 11-level system with examples of and information about each level.

The Soil System

The Soil System is recognized as an established, credible, hierarchical system that provides relevant information. It is an approach that utilizes the concept of the soil body as representative of an ecosystem and is identified at various levels of a hierarchy through the <u>Soil Taxonomy</u> (Soil Conservation Service 1975). Precedence for the basic concept can be found in the following statement:

> "About 1870 a new concept of soil was developed and introduced by the Russian school led by Dokuchaev (Glinka 1927). Soils were conceived by the Russian school to be independent natural bodies,

Order of Magnitude	Size In km^2	Designation	Examples	Basis
1	10^7	Realm	Continental Masses Oceanic basins	Magmatic differentiation Global geotectonics Geoclimatic
2	10^6	Major Division	Canadian Shield, Interior Plains, Intermontane Plateaus, Rocky Mountain System	History of geotectonic activity on a continental or oceanic basin scale
3	10^5	Province	Colorado Plateaus, Basin and Range, Great Plains, Southern Rocky Mountains, Blue Ridge	Major structural units exhibiting a characteristic history of development extending over the Cenozoic and perhaps the Mesozoic Eras. Large scale similarity of topographic or relief features
4	10^4	Section	Canyon Lands, Navajo, Mexican Highland, Sonoran Desert, New England Upland	Often affected by a single climatic zone, therefore, one environment or process usually dominant. Structural unit of limited Regional extent. May be restricted to a lithologic group.
5	10^3	Region	Mount Taylor, Volcanic Field, Gila Volcanic Field, San Juan Basin, Grand Canyon, Henry Mtn. Basin	Tectonic individuality often lithologic individuality often a single relief type Lower limit of isostatic compensation
6	10^2	District	Rio Grande Trench, Sierra Blanca Complex, Jemez - Caldera Complex, Sandia - Manzano Mountains. Mt. Taylor, Henry Mountains	Lithology influences tectonic style and pattern, also its interaction with a restricted geomorphic system
7	10^1	Area	Sandia - Manzano Piedmont, Valles Grande Caldera, McCarty Lava Flow	Interrelationships of lithology and surficial environments
8	Unit	Zone	Shiprock, Cabezon Peak Sandia - Manzano Pediment, Albuquerque Terrace, Karst Plain	Restrictive climatic controls and biotopes influencing specific lithologies. Its durability may have a limited time span
9	10^{-1}	Locale	Dunes, mudflows, silt holes, patterned ground point bars, pimple mount, slumpblock	Greater restriction of controls that determined its parent order 8 level landform. Lower limit for most mapping
10	10^{-2}	Compartment	Topographic elements or slope facets	More restrictive controls and limitation of parameters used in defining its superior landform. Time span may be extremely transitory. Main use is to provide diagnostic data used to interpret the genesis of its superior landform(s).
11	10^{-3}	Feature	Solution channels, stalagmites, ripple marks, splash impressions, worm burrows	

Figure 3.--Landform system showing the hierarchical classification based upon the geomorphic systems concept.

each with a unique morphology resulting from a unique combination of climate, living matter, earthy parent material, relief and age of landform. The morphology of each soil, as expressed by a vertical section through the differing horizons, reflected the combined effects of the particular set of genetic factors responsible for its development.

This concept made it not only possible, but necessary to consider all soil characteristics collectively, in terms of a complete, integrated, natural body, rather than individually" (Soil Conservation Service 1975).

The following material is a brief discussion of the soil system.

The soil body (as representative of an entire ecosystem of a component tessera) provides the conceptial framework for measuring the influence of the following factors (Buol et al, 1973; Carleton 1975[1]; Jenny 1958):

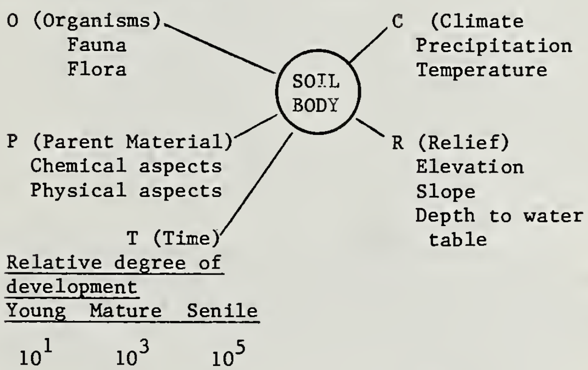

Diagram of Factors of Soil Formation

Therefore, this concept avoids the impossible task of trying to separate living material (nonsoil) from inanimate material (true soil), in an ecosystem where they interpenetrate inextricably (Buol et al 1973). The soil body as an ecosystem meets the concept stated by Odum: "The ecosystem is and should be a broad one, its main function in ecological thought being to emphasize obligatory relationships, interdependence, and causal relationships, that is, the coupling of components to form functional units." (Odum 1971).

A generalization of the primary influences of soil formation is expressed as:

Soil Body = f (O, C, R, T, P . . .)

when f = function

O = Organisms

C = Climate

R = Relief

T = Time

P = Parent material

The equation is most usefully interpreted to relate soil properties to factors in the entire ecosystem. Major concluded that these factors also determine vegetation (Major 1951). The significance of this concept is apparent when relating soils to vegetation and identifying ecosystems along a continuum.

The function of organisms, climate, relief, time and parent material on the soil body can be recognized through classes in the Soil Taxonomy. Direct measurement of all the climatic parameters associated with a particular soil is not always feasible.

Climatic boundaries are statistically determined boundaries, and as such, cannot be observed or mapped on the ground. "Climatic boundary on a map indicates only the mean position of numerous individual climatic-year boundaries which typically depart by hundreds of miles from the mean" (Trewatha 1968).

With this complication in mind, one must look for a realistic indicator of effective climate to associate with a particular soil. The most plausible approach is through the recognition of climate through key plants. "At least for those concerned with land use, the climatic vegetation map remains, therefore, one of the most realistic climatic records available today" (Kuchler 1967). Therefore, the soil moisture-temperature regimes in the Soil Taxonomy provide the gradients along a continuum for correlation with potential natural vegetation as identified at the Plant Series level. This results in one obligatory relationship between soils and vegetation. This relationship should be further manifested through physical and chemical properties of the soil body.

It should be emphasized that the state of the science is such that this relationship presently exists at a relatively high level within the Soil and Vegetation Systems. This point has led to much confusion when comparing vegetation and soil classification systems. Daubenmire (1970) expressed this concern by stating that, "in the steppe region of Washington there is no useful degree of correlation between vegetation classification and soil classification in their present states of development." It is anticipated that further

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1 Carleton, J.O. 1975. Soil body as an ecosystem. Unpublished manuscript. USDA Forest Service, Albuquerque, N.M.

research will reveal cause/effect relationships between soils and vegetation at.the more specific levels such as Plant Association/Soil Series.

Units of the Soil System are:

NAME	DEFINITION AND EXAMPLES
Level 7 (Phases of soil Orders)	Soils are identified through criteria at the Order level of the Soil Taxonomy and mapped as phases of soil orders. Example: Mapping Unit 335 Inceptisols - Alfisols association, 16-80 percent slopes
Level 6 (Phases of soil Suborders)	Soils are identified through criteria at the Suborder level of the Soil Taxonomy and mapped as phases of suborders. Example: Mapping Unit 334 Ochrepts - Boralfs association, 16-80 percent slopes
Level 5 (Phases of soil Great Groups)	Soils are identified through criteria at the Great Group level of the Soil Taxonomy and mapped as phases of soil great groups. Example: Mapping Unit 333 Cryochrepts - Cryoboralfs association, 16-80 percent slopes
Level 4 (Phases of soil Subgroups)	Soils are identified through criteria at the Subgroup level of the Soil Taxonomy and mapped as phases of soil subgroups. Example: Mapping Unit 332 Dystric Cryochrepts - Typic Cryoboralfs association, 16-80 percent slopes
Level 3 (Broad phase of soil Families)	Soils are identified through criteria at the soil Family level of the Soil Taxonomy and mapped as broad phases of soil families. Example: Mapping Unit 336 Dystric - Cryochrept, loamy-skel., mixed Typic Cryoboralf, loamy-skel., mixed, 16-80 percent slopes
Level 2 (Broad phase of soil Series)	Soils are identified through criteria at the soil Series level and mapped as broad phases of soils series. Example: Mapping Unit 331 Nambe cobbly loams, 0-15 percent slopes
Level 1 (Phase of soil Types)	This is the greatest degree of specificity within the soil system. Soils are identified through criteria at the soil type level and mapped as phases of soil types. Example: Mapping Unit 330 Nambe cobbly loam, 0-5 percent slopes Example: Mapping Unit 335 Nambe cobbly sandy loam, 0-5 percent slopes Example: Mapping Unit 336 Nambe stoney loam, 6-15 percent slopes

The Aquatic System

This Aquatic System agrees in concept with the original ECOCLASS document. It recognizes a hierarchical system that classifies different levels from a broad river system overview to a description of a segment of the smallest stream. It recognizes different aquatic conditions that, when classified and mapped, will be useful to the resource manager. It provides a base for descriptive information that can be used to describe the aquatic situation. While advocating the ECOCLASS method, this sytem makes some changes in the original document.

At the broader levels (Order, Class and Family), descriptions can only be expressed in general terms, such as whether waters are cold-warm, salt-fresh, clear-turbid and basin-wide streamflow data.

The AQUATIC-TYPE ASSOCIATION is the first level at which waters will be individually classified and the broadest classification that provides descriptions useful to resource management at the National Forest/Ranger District level. Such descriptions will be generally available from existing inventories and stream/lake surveys, either in-Service or from cooperating agencies. Little, if any, field work should be needed at this level and mapping could be accomplished on 7.5' series topographic maps.

Stream ordering (not to be confused with Order in the hierarchial classification) offers a relatively simple procedure for classifying streams in a way that is generally useful to land planners and managers. Using the 7.5' series topographic maps, this procedure designates all unbranched tributaries as first order streams. The order is increased each time two streams of the same order merge. Thus, streams of the same order will exhibit generally similar ecological characteristics. However, there can be significant differences between streams of

the same order in such factors as length, gradient and geology.

Lakes and reservoirs should be classified separately since reservoir operation drastically affects ecological characteristics. Both groups could then be further classified according to size (surface-acres), since the productivity and capacity for various uses are directly related to water surface area.

Beaver ponds should be segregated from other standing water bodies because they fit into a different ecological niche, based on such factors as size, depth and permanency. A further breakdown that may be useful for intensive planning purposes would provide separate classification for those on-stream ponds that are fed by surface flow as compared to seepage ponds sustained by subsurface water. Also, according to Shaw and Fredine (1956) some beaver ponds may fit best into one of the classifications for wetlands, which include wetland types:

1. Seasonally flooded flats
2. Fresh meadows
3. Shallow, fresh marshes
4. Deep, fresh marshes
5. Open fresh water
6. Shrub swamps
7. Saline flats
8. Saline marshes
9. Open saline Water

For the most intensive planning efforts, streams and lakes should be classified to the AQUATIC-TYPE. This will involve collection of data in the field, most of which will require the services of a specialist - such as a hydrologist or a biologist. Data collected will often involve measurement and analysis of transects (cross-sections) located at a point on a stream considered critical to the plan under consideration.

Where needed, detailed biological data will require close cooperation with appropriate wildlife agencies. An example of this would be an electro-fishing survey to supply information on fish species composition or fish standing crop. Estimates of annual fish harvest (or fishermen/visitor days) would require field work to obtain an adequate sample upon which a season-long projection can be made. A stream survey would be necessary to obtain such pool-riffle ratio information. However, it will not be necessary to obtain such detailed data for most National Forest programs.

Field experience may disclose a factor not listed that is more useful in describing a certain level than some of the factors shown in the proposed system. There should be no hesitancy in either using different factors or the same factor at a different hierarchical level.

Much work has been done in other fields, such as vegetation classification, to define and refine the criteria necessary for adequate classification. The criteria for the Aquatic System classification will take time to perfect. Several sciences have been involved, but no classification has evolved with general acceptance and use. More effort is needed to determine which environmental elements should be used to fully describe individual water bodies or portions thereof.

The following proposed classification provides an outline of the Aquatic System. There are no strong commitments concerning labels and definitions.

NAME	DEFINITION
Aquatic Order	Water Resource Regions created by the Water Resource Council under provisions of the Water Resources Planning Act (PL 89-80). The Water Resource Regions are documented in the Atlas of River Basins of the United States, prepared by USDA, Soil Conservation Service.
Aquatic Class	River basins of the United States having drainage areas of more than 700 sq. miles. The Atlas of River Basins of the United States, prepared by USDA, Soil Conservation Service, contains the boundary and locations of these river basins.
Aquatic Family	Sub-basins of Aquatic Class River Basins that have been identified in Forest Service Manual 2573.
Aquatic Type Association	Division as to standing water or moving water. Moving water is classified by stream order as defined by Horton and slightly modified by Sehrahler in Chow (1964). Streams are ordered beginning at the head of a watershed with the smallest identifiable drainage on U. S. Geological Survey 7.5' topographic maps or 1:24,000 aerial photographs. Stream orders may be later described as being perennial, intermittent or ephmeral in nature. Stream order procedures are from Chow (1964).

	Standing water is classified into the following categories: Natural lakes, reservoirs, beaver ponds or wetlands.
Aquatic Type	Division of aquatic type associations into reaches of moving water or zones of standing water.
	Moving water at the aquatic type association may be broken into reaches based on criteria of: gradient, pool-riffle ratio, inflow-outflow and flood plains.
	Standing water at the aquatic type association may be broken into zones based on inflow-outflow relationships, temperature or chemical stratification, and phototrophic characteristics.

CONCLUSION

Application of Modified ECOCLASS will require detailed training of field personnel to acquaint and align them with the concepts and objectives of the method, and with mapping and normal data gathering procedures using aerial photographs. Currently, reasonably adequate information is available at the higher level categories of all systems to provide data needed for implementation of the method of those levels. However, at the lower levels, especially at the Plant Association, Landform Compartment and Feature Levels, Soil Series and Type Levels, and Aquatic Type, significant research is needed to identify classification criteria for those units within the framework of their respective hierarchies. A team approach is the most feasible way to do this work and is especially necessary in the characterization, interpretation and mapping of Ecological Land Units and Ecological Water Units.

It must be recognized that classification criteria and application of Modified ECOCLASS are dynamic. As research and experience make new discoveries, the method will be modified and updated.

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Land Classification as a Base for Integrated of Renewable Resources Inventories[1]

Philip Gimbarzevsky[2]

Abstract.--The biophysical land classification system presently used in Canada, is an integrated approach to environmental inventory, based on the recognition of landscape characteristics as an ecological framework for the evaluation of natural resources. Development of this system, its hierarchical structure and application in current surveys is described and illustrated with selected examples.

INTRODUCTION

The need for an orderly grouping of earth surface areas by a set of criteria or some common characteristics evolved as a response to the increasing demands for natural resources and growing concerns for the maintenance of environmental quality. Foresters, as managers of the most precious natural resource, have recognized that the forest is an integral part of the ecosystem and its occurrence, structure and growth are intimately linked with the physical character of the landscape. Management of the forest is actually management of forest land, that requires, in addition to the essential information on the amount, quality and extent of forest cover, also a comprehensive knowledge of the physical characteristics of the land, its biological capacity or limitations, past and present land use practices, distribution of wetlands, water bodies, etc. To provide land information for expanding agriculture and forestry, several classification schemes were developed in Canada during the past 50 years, based on three general concepts: pedological, developed for soil surveys, phytosociological, developed for determination of forest site classes, and physiographic, developed for determination of forest sites and for multi purpose land classification (Rowe, 1962, Lacate, 1962, Burger, 1972). All three concepts have contributed to the development of the biophysical land classification system, presently used in Canada.

[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan. 8-12, 1978.

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This paper consists of two parts. The first part covers a general review of the pedological, phytosociological and physiographic concepts, and describes in more detail the application of physiographic attributes for determination of land capability classes. The second part describes the hierarchical structure of the biophysical classification system developed by the National Committee on Forest Land, and demonstrates its application in current integrated surveys of natural resources.

LAND CLASSIFICATION CONCEPTS

Pedological Approach

This classification approach initiated in the nineteen twenties for the soil surveys of agricultural land, is based on the general concepts of great soil groups and soil series. In 1960 it was finalized as a comprehensive classification scheme by the National Soil Survey Committee and adopted for official use by all soil survey organizations in Canada.

The Canadian taxonomic classification is based entirely on soil profile characteristics. It has six categories: order, great group, subgroup, family, series, and type. The three highest categories (order, great group and subgroup) deal specifically with concepts and variations of kinds of soil profiles, relating in particular to the recognitions of soils having morphological features that reflect similar pedogenic environments. The three lower categories (family, series and type) are based on profile characteristics that reflect features of parent material and texture.

The soil series is the principal unit of soil classification and mapping, and is defined

as a group of soils that are essentially alike in all major profile characteristics including kind of parent material. It has the same number and arrangement of horizons, whose color, texture, structure, consistence, thickness, reaction and composition, or a combination of these are within a defined range.

Soil series may be divided into soil types on the basis of the texture of the soil (Clayton et al. 1977).

Soil survey maps at the series level are available for most of the settled parts and for some northern areas of Canada. Compiled jointly by the federal and provincial governments, research councils and universities explicitly for agricultural purposes, the soil maps have been for a long time (and in some areas still are) the only source of reliable information on land resource.

Phytosociological or Ground Vegetation Approach

This approach, based on the recognition of plant communities as an indicator of the land's productive capacity was introduced in Canada in the late nineteen twenties for the evaluation of forest land in terms of "site types" and "site classes". A site type in this classification was defined as the complex of physical and biological factors which determine the kind and quality of vegetation the area can carry. The qualitative characteristics of a site are expressed as site classes, determined from the "site index", or the height of dominant and codominant trees in a stand at specified age.

The site classification studies, initially based on purely floristic characteristics determined by the Cajander's method, were often adapted to regional conditions by relating ground vegetation to other site factors, such as for example, soil types, moisture regime, elevation, microclimate or parent material (Burger, 1972).

Physiographic Approach

The physiographic approach to land classification is based on the interrelationship of physical land features with climate, soils and vegetative cover. The advances in aerial photography, followed by the development of air photo interpretation techniques allowed a systematic study of the land surface and recognition of landforms resulting from geomorphic processes of deposition and erosion. The concept of landforms, developed and successfully used in the United States in the early forties to classify and map soils from aerial photographs, for engineering purposes (Belcher 1943, 1948, Jenkins et al., 1946), was applied in Canada for mapping forest sites (Losse, 1942, Hills, 1950). The recognition of landforms provided a base for the physiographic approach of the Ontario site classification system, and land capability classification for various uses.

The Ontario Site Classification System

The physiographic system, developed by Hills and his Associates in Ontario to describe, classify, map and evaluate potential land productivity, recognizes the climate, kind and depth of geologic material, soil moisture and soil profile as the physiographic features which form the basis of this classification (Hills and Pierpoint, 1960).

In the development of this hierarchical taxonomic classification system, the physiographic characteristics of ecosystems are used as a stable base for the evaluation of the land's productive capability for multiple use. The four levels of hierarchical structure are site region, land type, physiographic site type and site condition.

Site regions are areas within which specific plant successions occur upon specific landform positions. There are twelve site regions in Ontario that can be considered as climatic regions from the viewpoint of forest production.

A land type is an area of a certain type within a particular site region classified on the basis of broad classes of texture of parent material, mineralogical composition, depth to bedrock, or broad classes of rock weathering.

Physiographic site type is a subdivision of the land type, defined by the soil moisture regime, local climate and variations in soil depth within the land type. The physiographic site types are the basic homogeneous areas used as a basis for rating potential productivity.

Site condition refers to the condition of the upper soil horizons, particularly of the organic and mixed organic-mineral layers, at each individual area within any one particular physiographic site. Variations in site conditions are expressed as four "condition classes", from "best" to "very poor".

Land Capability Classification

The general concept of the Ontario site classification system provided a fundamental framework for a further development of the physiographic land classification in Canada. With the expanded use of aerial photography the physiographic approach has been applied as

a practical method in a systematic mapping of physical characteristics of a landscape to provide a firm base for determination of the land's biological productivity or its suitability for a specified purpose. This approach was used by industry and government agencies for various operational purposes, such as the establishment of forest management units based on land capability, selection of highly productive sites for intensification of silvicultural practices, or to classify soils according to their engineering characteristics for planning and construction of main roads (Brown, 1956, Gimbarzevsky, 1964). More recently, in 1963, the physiographic land classification approach was used to provide a comprehensive base for the nationwide land inventory for integrated land use and resource planning in Canada.

The Canada Land Inventory program initiated in 1963, was designed to classify the lands within the settled parts of Canada comprising an area of almost 2,500,000 km^2 (about one million square miles) as to their capability for use in agriculture, forestry, wildlife and recreation (McCormack, 1965). The classification system, developed through pilot studies in each province and frequent consultations of federal, provincial and university specialists, was designed as an interpretative grouping of land units according to natural land characteristics and an assessment of their influence on biological productivity or suitability for various uses. Due to the large size of the area, extending through major physiographic regions of Canada between the Atlantic and the Pacific, the classification was based to a large extent, on the interpretation of aerial photographs.

Two major efforts were involved in the development of photo interpretation techniques for this inventory program:

- the recognition of physical land features, and
- the evaluation of their effect on the productivity range, or land suitability for a particular use.

Basic information on the physical land characteristics was obtained by a conventional analysis of landscape pattern and recognition of landforms, while the productivity range or land suitability of various landforms, was established empirically from ground data or pilot studies (Gimbarzevsky, 1967).

The capability rating in the CLI program is a deductive process: on the basis of recognized physical characteristics the land surface is separated into homogeneous units, classified, and placed in one of the seven capability classes for agriculture, (CLI, 1965), forestry, (McCormack, 1965), wildlife, (Perret, 1969) and recreation (Brown, 1966). Each capability class has a specified productivity or suitability range, in a decreasing order from class 1 to class 7. This productivity or suitability range is a function of climate and the physical properties of the land. Within a regional climate, the land's productive capacity or suitability is controlled mainly by topography and surficial material — its minerological composition, texture, depth to underlying bedrock, moisture conditions and other natural or man-made environmental factors that may be beneficial or detrimental to a particular use. One land unit, for example, may have a high capability class for a production of commercial forest, but a marginal value for agricultural field crops due to its topography (Gimbarzevsky, 1972).

BIOPHYSICAL LAND CLASSIFICATION

The biophysical classification system is essentially a synthesis of existing land evaluation schemes, developed by the National Committee on Forest Land to provide an ecological base for multiple land use planning in areas not covered by the CLI program. It is an integrated approach to environmental inventory based on Rowe's concepts of ecosystems (Rowe, 1962) and an adaptation of the land classification system developed in Australia (Christian and Stewart, 1968, Stewart, 1968). The land is considered as the whole vertical profile from the atmosphere above the surface to the underlying geological horizons, where climate, landform, soil, water, vegetation and organisms are interrelated environmental factors. The physical factors — climate, landform, soil and water form a firm physiographic base for the evaluation of biological resources. In actual application of the biophysical approach, the landform classification and mapping provide the framework within which climatic, vegetational, pedologic and hydrologic data are described and classified (Jurdant, et al., 1973).

Classification Levels

There are four classifications levels arranged in a hierarchical order to express the intensity of integration of delineated map units: Land Region, Land District, Land System and Land Type (Lacate, 1969).

A Land Region, at the top of this hierarchical order, is usually an extensive area consisting of several contiguous landscapes, with a complex of physiographic patterns characterized by a distinctive regional climate as expressed by vegetational complexes. Due to their size, the Land Regions may be best mapped at small scales of 1:1,000,000 to 1:3,000,000 using satellite imagery, small-scale photography or photo mosaics.

A Land District is a component of a Land Region, characterized by a distinctive pattern of relief, geological structure, geomorphic evolution and associated regional vegetation. The separation of Land Districts is based primarily on the recognition of major physiographic and geological macro-features characterized by a common pattern of relief, elevation, bedrock geology or landform. A convenient mapping scale is 1:250,000 to 1:1,000,000.

A Land System, as a component of a Land District is characterized by a recurring pattern of landforms, soils and vegetation. Land systems may be mapped at scales of 1:100,000 to 1:250,000.

A Land Type is a component of a Land System, delineated as a topographic unit occurring on a particular type of parent material. It has a fairly homogeneous combination of soil texture, drainage and a succession of vegetation. The land type is a fundamental land classification unit, mapped at scales of 1:10,000 to 1:50,000, that is used as a base for rating the biological capacity and is also used for other resource management purposes.

Application

The application of this classification is based on a systematic stratification of the land surface into ecologically significant segments composed of a pattern of landforms, vegetation and water bodies. Since distribution, kind and quality of natural vegetation is closely linked with the physical aspects of the landscape, the land features are mapped first to provide a base independent of successional changes, for the evaluation of biological components.

Following the successful completion of pilot studies, several operational surveys have been conducted in various parts of Canada to provide an ecological framework for multiple land use planning, assessment of environmental impacts, or resource management (Thie and Ironside, 1976). The general guidelines proposed by the National Committee on Forest Land (Lacate, 1969) have been found quite suitable for a rapid reconnaissance of extensive land areas and for more detailed evaluation at the Land System or Land Type levels.

The selection of adequate survey-intensity level depends on the purpose of the survey. Reconnaissance at a Land Region level, for example, provides a rapid analysis of broad physiographic patterns and an overview of extensive areas at a convenient small scale of 1:1,000,000 or smaller. Such an overview permits a preliminary evaluation of physical and biological landscape components which can be applied in broad planning or used to identify specific areas for more intensive surveys at the Land System or Land Type levels.

Regardless of the intensity level, the general approach to an integrated inventory of the principal natural resources — land, vegetation and water, involves three main work phases: a. resource data acquisition, b. presentation and c. interpretation.

a. Resource Data Acquisition

Resource data acquisition includes preliminary work, systematic air photo analysis and classification and field verification.

The preliminary work consists of gathering, reviewing and integrating existing information on bedrock geology, geomorphology, soils, vegetation, climate, land use, hydrology, aerial photography, maps and other material related to the area to be surveyed.

A systematic analysis of aerial photographs, air photo mosaics, Landsat and other remote sensing imagery has been found to be an extremely useful means to delineate landscape patterns and establish a broad framework based on the recognition of geomorphic processes. Landsat imagery and small scale conventional photography are quite adequate for the recognition of general physiographic features and associated vegetation patterns from which Land Regions or Land Districts can be delineated.

The Land Systems are recurring patterns of landforms, delineated on intermediate scale aerial photographs (1:30,000 to 1:50,000) as simple or compound land units, occupying an area of some 2 km^2 or more. A simple land system is made up of a single landform, as for example a relatively homogeneous marine plain, or an extensive organic depression. A compound land system, which is most common, consists of several landforms where, in addition to a dominant landform, there occur two or more other landforms intimately intermixed, forming a complex landscape pattern, as for example a drumlinized plain, which in addition to drumlins, may include organic-filled depressions, portions of flood plain, and other small landforms. A land system is identified by a uniform regional climate, a characteristic relief, geomorphic origin, drainage conditions and associated vegetational complex.

The land types are land units characterized by a relatively homogeneous combination of soils, topography, drainage conditions, geomorphic origin of parent material and chronosequence of vegetation. Land types, as fundamental units for resource management, are identified on medium or large scale aerial photographs by <u>local topography</u>, <u>soil texture</u>, <u>drainage class</u>

and geomorphic origin of parent material. Local topography is a component of the general relief pattern and expresses a particular surface configuration of a land unit — its dominant smoothness or roughness, type of slope and degree of incline, or steepness class. Soil texture of a land type is expressed as seven texture classes — from very coarse, which includes sand and gravel, to very fine (clay). Drainage condition or moisture regime of a land type is a combination of local climate, surface runoff and internal drainage or permeability. The soil texture and depth to underlying bedrock control the permeability, while the rate of surface runoff is a function of topographic features, internal drainage and vegetative cover. From the analysis of these parameters the moisture regime of a land type is expressed as six drainage classes. Classes 1 and 6 are two extremes: Class 1 indicates a rapid runoff and/or high permeability, and generally "dry" moisture conditions, while Class 6 indicates very wet, saturated conditions, due to poor permeability, lack of surface runoff, or both.

Geomorphic origin of a land type is determined from the analysis of landforms and recognition of significant processes of deposition and erosion performed by the glacier, water, wind, gravity or a combined action of these forces. To provide additional information on physical characteristics of surface material that may indicate some inherent soil properties related to land capability or limitations the land types are identified as glacial (till, fluvial, lacustrine), waterlaid, aeolian, organic, marine, gravity or bedrock.

The field verification, or collection of ground data in general is an integral part of biophysical survey. As the field work is usually the most expensive portion of any survey it requires proper planning and preparation. All essential field observations on physical land features, forest cover, non-forest plant communities, water bodies, shorelines, etc. are recorded either along predetermined transects or in selected localities. Samples of plants and soils, ground photographs, slides, strip aerial photography from helicopter, and other field documentations on some specific aspects of the area provide valuable support for the final classification and validity of survey data.

b. Resource Data Presentation

Presentation of resource data involves the preparation of base map(s) at a suitable scale, transferring of resource details from interpreted aerial photographs to the base, and compilation of resource map(s). The map scale is dictated by the survey intensity and the resulting size of land units to be presented. The Land Regions or Districts occupying an area of several thousands of square kilometers may be shown at the scales of 1:1,000,000 or smaller, while larger scales are required for an effective presentation of Land Systems and Land Types (Gimbarzevsky, 1976).

The base maps for a cartographic display of survey results, at a suitable scale, are usually compiled on a stable transparent material as line maps, photo mosaics or photo maps.

The following examples illustrate the presentation of resource information at regional reconnaissance (Land, Region and Land District), Land System and Land Type levels.

Regional Reconnaissance.--Land regions and districts, are large map units, presenting a broad overview of macro-features related to regional climate, physiography, geology, vegetation and glacial history of the area. In the reconnaissance survey of the Yukon Territory, for example, the entire area comprising over 480,000 km^2 was subdivided into 22 "Ecoregions" ranging in size from less than 5,000 km^2 to over 42,000 km^2 (Fig. 1). The boundaries of "Ecoregions" were delineated on 1:2,500,000 scale Landsat mosaic and each unit, named after a prominent geographic landmark, was briefly described in terms of physiography, drainage, geology, climate, glaciation and surficial deposits, terrain features and vegetation (Oswald and Senyk, 1977).

Land Systems.--Land systems delineated as recurring patterns of landforms may be presented at the scales 1:50,000 or 1:100,000. In the biophysical survey of some 24,000 km^2 in the Lac Saint Jean area in Quebec the land units, delineated as land systems and having an average size of 10 km^2, were effectively presented at the scale of 1:125,000. Essential data describing the major ecological characteristics of each unit were expressed by a six-digit symbol, consisting of letters and numerals, to indicate:

- Land Region in which the system is located;
- Topography (mountainous, hilly, rolling, undulating or flat);
- Depth of unconsolidated surficial material (deep, shallow, bare, and their complexes);
- Dominant group of landforms within the system (e.g. thick or thin till, glaciofluvial, deltaic, fluvial and lacustrine, moraine, beach, organic, slope, wind and bedrock deposits);
- Reference to a detailed description of the land system;
- Presence or absence of significant water bodies within the land system (Jurdant et al., 1972).

A similar approach, with a slight modification, is presently being used by the Forest

Figure 1. Regional reconnaissance and delineation of broad "ecoregions". Features related to physiography, climate, drainage, bedrock geology, glacial history, surficial deposits and vegetation are described for each ecoregion. Portion of Landsat mosaic, Yukon Territory, Scale 1:2,500,000.

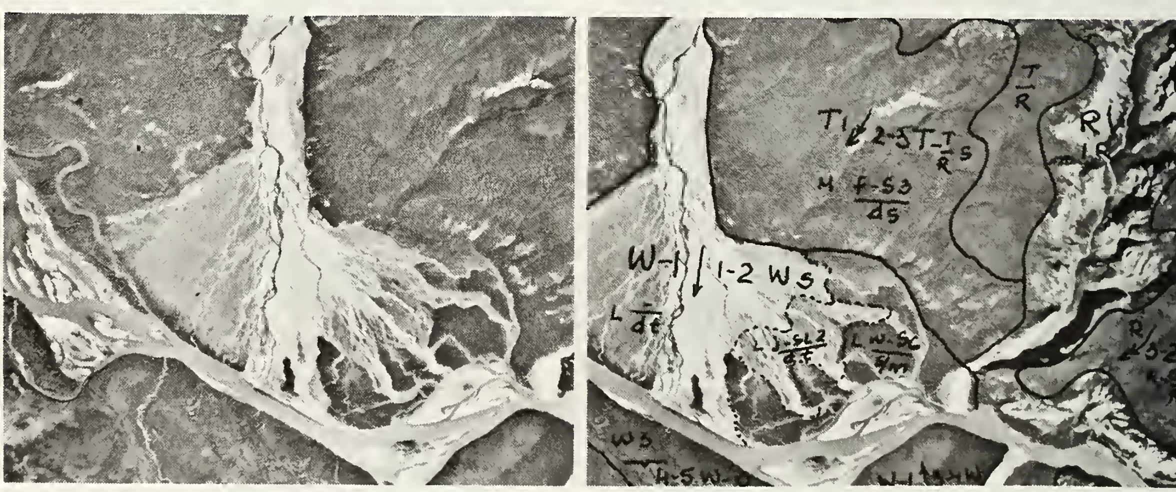

Figure 2. Land systems delineated as recurring patterns of landforms. A stereogram, scale 1:60,000. Location: NTS map sheet 95F-8, South Nahanni River area, N.W.T. Geomorphic origin of dominant surface material, topography, drainage conditions, aspect and vegetation pattern are expressed by simple symbols.

Management Institute (FMI) for an integrated survey of some 5000 km^2 of wilderness area in the Northwest Territories (South Nahanni National Park). The land systems (average size about 2.5 km^2) are presented at the scale of 1:50,000 (Fig. 2), with the map symbols expressing the following information:

- geomorphic origin and depth of dominant material (till, fluvial, lacustrine, alluvial, organic, aeolian, colluvial, bedrock and snowfields);
- dominant topography (sharp or steep variable, sharp or steep constant, moderate variable, moderate constant, flat variable and flat constant);
- drainage conditions (excessively dry, dry, moderate to fresh, imperfect, poor, very poor);
- aspect;
- vegetation (life zones, vegetative structure and composition).

Land Types.--Land types are relatively small map units delineated as homogeneous components of a land system and presented at the scales 1:25,000, 1:10,000 or larger. This survey level intended for management purposes provides more specific information on physical land characteristics expressed as predetermined classes of local topography, moisture conditions, soil texture, origin of surface material and depth to underlying bedrock. The symbolization developed at FMI (Fig. 3) has been found quite convenient for mapping at the land type level: local topography is presented graphically by a symbol resembling the shape of a particular surface configuration, the soil moisture classes are indicated by numerals 1 to 6, while the texture classes are indicated as lower case abbreviations (vc - very coarse, c - coarse, mc - moderately coarse, etc.). The geomorphic origin of a land type is expressed by upper case letters (e.g. T - till, F - glaciofluvial, A - aeolian, etc.).

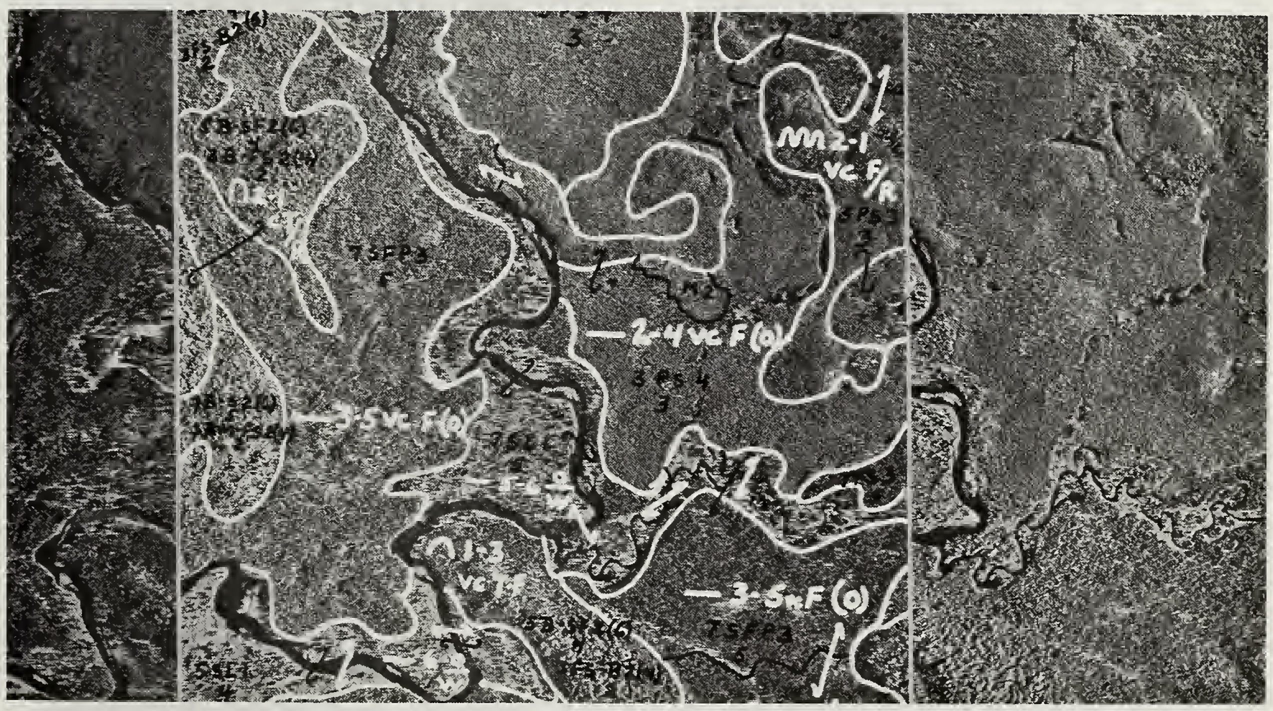

Figure 3. Land types (white lines) delineated as relatively homogeneous map units characterized by common features of local topography, soil texture, drainage class, origin of parent material and depth to underlying bedrock.
Present vegetation (black lines) within each land type is classified by species composition, density, height, and condition classes.
A stereogram, scale 1:15,840. Location: NTS 42D-9, Ontario.

Vegetation types - forest cover types, stratified by density, height and species composition, and non-forest plant communities may be presented as composite land-vegetation map (Fig. 4), or as separate overlays (Gimbarzevsky, 1975).

c. Interpretation of Biophysical Data

The survey results provide essential information on the kind, location and areal extent of primary natural resources of an area and their basic characteristics, expressed in a simple form as map units at a desired level of integration. These basic characteristics and their positive or negative effect on the suitability of the map unit for a particular purpose may be interpreted from the resource maps and expressed in a form suitable for a specific purpose, such as:

- Land capability for biological productivity; (e.g. agricultural crops, timber production, logging practices, silvicultural treatment wildlife habitat, environmental impact, etc.).
- Land suitability for recreational uses (e.g. landscape attractiveness, unique scenic setting, water bodies, etc.).
- Land suitability for engineering uses (e.g. engineering soil characteristics, granular material, construction sites, slope stability, erosion, etc.).
- Water as landscape component (e.g. character of streams and lakes, shoreline features, drainage basins, sedimentation etc.).

CONCLUSIONS

The biophysical approach to resource evaluation is now beyond the experimental stage, and in spite of some variations in method, its application in several operational projects has provided encouraging results. As a successor to the National Committee on Forest Land, the Canada Committee on Ecological (Biophysical) Land Classification is presently charged with the responsibility to coordinate the continued development of a Canadian Land Classification System.

The concept of hierarchical structure of this system is particularly suitable for integrated surveys of large inaccessible areas in northern parts of Canada, often lacking any kind of resource information. To provide basic data, the work may commence, for example, as a broad reconnaissance, based on the evaluation of general landscape patterns, then proceed toward more detailed examination of some specific components of this pattern. It has also some practical advantages. It allows the most effective use of remote sensing technology,

Figure 4. A composite land-vegetation map. Land types are shown as heavy lines, while vegetation types as half-tone, fine lines. Scale 1:12,500. Portion of NTS map sheet 21A-6, Nova Scotia.

eliminates or reduces costly duplication of resource data acquisition efforts, and has a "built-in" provision to integrate subsequent more intensive investigations into previously completed reconnaissance surveys.

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The USGS Land Use and Land Cover Classification System[1]

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Abstract.--The USGS land use and land cover classification system was devised to provide a logical framework when such information is derived from remote sensors as well as serving as the classification system to be used in a national inventory. The result is a combination of inductive logical processes (remote sensor image interpretation capabilities) and deductive logical processes (division of the landscape as related to resource information needs).

DEVELOPMENT OF THE USGS LAND USE AND LAND COVER CLASSIFICATION SYSTEM

In 1972 the U.S. Geological Survey published Circular 671, entitled "A Land Use Classification System for Use with Remote-Sensor Data" (Anderson, and others, 1972). The classification system proposed in Circular 671 was devised for two principal purposes: 1) to provide a logical framework for presenting land use and land cover information that could be derived primarily from remote sensors and which could be applied to land resource planning and management in many situations throughout the United States at various levels of government; and 2) to serve as the primary vehicle in a national land use and land cover map and data program, currently being carried out by the U.S. Geological Survey.

Every classification that is more than an academic exercise has an objective that extends beyond the creation of the classification system itself. A city's zoning classification is created in order to control and plan the city's development and to organize the municipal services supplied to the various zones. Students' aptitudes are tested and classified so that they may be properly directed toward curricula suited to their interest and abilities. Similarly, the USGS classification system was created to provide systematic information on land use and land cover occurrences and patterns in order that resource planning and decisionmaking might become more efficient and standardized.

Past efforts at land use and land cover data collection and inventory have been uncoordinated among the various levels of government and jurisdiction. In such a situation, no acceptance of standardized classification or definition was possible. There was no relationship between data gathered to make some particular decision and the compatability or systematic needs of such data over time. The national land use and land cover map and data program was conceived in order to fill the need for a baseline set of maps and data that could be used for several objectives related to resource management. In meeting such objectives, it was necessary to construct a classification system having several hierarchical levels which could be related to the levels of decisions being made, i.e., national, State, regional, local, etc.

Increasing resource demands and increasing technical capabilities have made it both imperative and possible for many of the land use and land cover information needs of various governmental agencies and private organizations to be met more efficiently, systematically, and comprehensively through the interpretation of data gathered by remote sensor devices aboard

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aircraft and spacecraft. The cost-effectiveness and capabilities of modern remote sensing technology necessitated its use as the primary data source for the present USGS program of initial mapping and compilation of maps and data on current land use and land cover, and for the updating of such maps and data.

The USGS land use and land cover classification system was devised with the following criteria in mind (Anderson, 1971):

1. The minimum level of interpretation accuracy in the identification of land use and land cover categories from remotely sensed data should be at least 85 percent.

2. The accuracy of interpretation for the several categories should be about equal.

3. Repeatable or repetitive results should be obtainable from one interpreter to another and from one time of sensing to another, possibly several years later.

4. The classification system should be applicable over extensive areas.

5. The categorization should permit vegetation and other types of land cover to be used as surrogates for activity.

6. The classification system should be suitable for use with remotely sensed data obtained at different times of the year.

7. Effective use of subcategories that can be obtained from ground surveys or from the use of larger scale or enhanced remote sensor data should be possible.

8. Aggregation of categories must be possible.

9. Comparison with future land use data should be possible.

10. Multiple uses of land should be recognized when possible.

Some of these criteria apply to the process of land use and land cover classification in general, and others apply primarily to land use and land cover data interpreted from remotely sensed data.

Several other "ground rules" were observed during the creation of the classification system, in addition to the assumed need for primary reliance on remotely sensed data inputs for practical implementation and use of the system. These included: the desire to employ features, categories, and definitions of existing systems to the fullest extent possible, in order to maintain as much historical continuity of data as possible; the need for complete categorization of 100 percent of the land; the need for the classification to be both open-ended and flexible so that additional levels of categorization could be added and defined in such a way that different regional land use and land cover occurrences or data needs could be accommodated but at the same time provide a framework for standardization.

USGS Circular 671 was published as a review document. Because of that intent, and because of the increasing interest in land use topics over the past few years, Circular 671 became one of the most requested circulars ever released by the U.S. Geological Survey. During the period 1973-75, the classification presented in Circular 671 was subjected to extensive review and testing. It was reviewed formally by all major resource managing and data gathering Federal agencies; by many similar State and local agencies; and by several hundred researchers and interested individuals in government, private enterprise, universities, and foundations. A nationwide series of workshops dealt with the classification itself and the land use classification process in general. In addition, several variations of the classification were tested in regional mapping and demonstration projects covering more than 130,000 mi.^{2} in western, central, and eastern areas of the United States. The results of this review and testing were incorporated into a revision of the classification system, published in 1976 as USGS Professional Paper 964, "A Land Use and Land Cover Classification System for Use with Remote Sensor Data" (Anderson and others, 1976). Levels I and II of the system are presented in table 1. Professional Paper 964 should be consulted for a more detailed account of the historical development of the classification system, discussions of the need and use of such data, and detailed definitions of the land use and land cover types classified in Levels I and II.

Table 1.--U.S. Geological Survey land use and land cover classification system for use with remotely sensed data.

1	Urban or Built-up Land	
	11	Residential
	12	Commercial and Services
	13	Industrial
	14	Transportation, Communications and Utilities
	15	Industrial and Commercial Complexes
	16	Mixed Urban or Built-up Land
	17	Other Urban or Built-up Land
2	Agricultural Land	
	21	Cropland and Pasture
	22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23	Confined Feeding Operations
	24	Other Agricultural Land
3	Rangeland	
	31	Herbaceous Rangeland
	32	Shrub and Brush Rangeland
	33	Mixed Rangeland
4	Forest Land	
	41	Deciduous Forest Land
	42	Evergreen Forest Land
	43	Mixed Forest Land
5	Water	
	51	Streams and Canals
	52	Lakes
	53	Reservoirs
	54	Bays and Estuaries
6	Wetland	
	61	Forested Wetland
	62	Nonforested Wetland
7	Barren Land	
	71	Dry Salt Flats
	72	Beaches
	73	Sandy Areas Other than Beaches
	74	Bare Exposed Rock
	75	Strip Mines, Quarries, and Gravel Pits
	76	Transitional Areas
	77	Mixed Barren Land
8	Tundra	
	81	Shrub and Brush Tundra
	82	Herbaceous Tundra
	83	Bare Ground Tundra
	84	Wet Tundra
	85	Mixed Tundra
9	Perennial Snow or Ice	
	91	Perennial Snowfields
	92	Glaciers

Inconsistencies are likely to occur in any pragmatic classification system, and the USGS system is no exception. Inconsistencies in the USGS classification are the result of compromises in user needs, not the abilities of remote sensor devices. The inconsistencies themselves are actually grouping differences, not functional deficiencies, and can be resolved by the user through re-aggregation. For example, adding Forested Wetland to Forest Land allows the user to obtain the total area of all forest land.

PRINCIPLES AND PROCEDURES OF CLASSIFICATION

Most writers (see, for example, Sokal, 1974, and Grigg, 1965) agree on the three basic purposes of classification:

1) to give names to objects and groups of objects;
2) to transmit information about those objects;
3) to allow generalizations to be made about the objects.

As Grigg (1965) states: "Classification is the grouping of objects into classes on the basis of properties or relationships they have in common. Such a grouping can be reached by two distinct methods, classification and division." The inherent difference between these two methods can be simply reduced to whether an inductive logical process or a deductive logical process is applied. In the former method (classification), each object is examined individually, and some property (or properties) of that object is utilized as the criterion (or criteria) for relating it to other objects. As an example, parcels of forest land, all having the same particular species composition, might be assigned to different classes on the basis of their stocking or condition. These classes may then be further aggregated into larger classes on the basis of species composition. All species classes might be classified as being deciduous or coniferous, and these two classes grouped together to account for all forest land. In such an inductive process the entire range of possibilities of forest types are not examined, nor are all of the possible properties considered which could be used as criteria in assigning forest land parcels to classes at the various levels. Such a procedure frequently results in the need to re-examine the use of particular criteria in order that the relative importance of the criteria be properly adjusted to the hierarchy created (the reader is encouraged to utilize the classification principles set forth by Grigg, 1965, p. 468-469).

In the latter method (division or "logical division" as it is known among taxonomists) a class is created which includes all possible occurrences being considered (in our case, the land) and that class is successively subdivided into hierarchical levels on the basis of the fundamental principle underlying the need for the classification (in our case, the cover on the land or the use which can be inferred or interpreted from the cover). In this deductive process of logical division, the entire range of uses and cover types must be considered before creating classes. This characteristic makes such a classification applicable to the entire area or region under consideration.

Even though classification and logical division have just been described as distinctly different processes, they are nonetheless closely associated and produce essentially the same result if applied properly: a hierarchical classification system. In most practical applications during the creation of classification systems, the taxonomist uses both inductive and deductive methods. With respect to the land, he gains his knowledge about possible occurrences of types of land use and land cover (or other criteria for classification) inductively through field experience, examination of aerial photographs or other remote sensor images, or analysis of other data. He then devises (or as some authors suggest, contrives, since all classification systems are man-made creations for one purpose or another) a classification system by either aggregating or logically dividing the land use or land cover types observed. Typically, this process goes through several iterations, until the proper criteria for hierarchical aggregation or subdivision become apparent.

The process just described is basically what has taken place over several years of research and review which preceded the publication of USGS Professional Paper 964, and is still taking place. At the same time that researchers were attempting to find out which types of land use and land cover could be interpreted (inductive stage) from remotely sensed images of various types and various scales, the information needs of resource-oriented agencies at the various levels of government and other organizations were being examined. It was quickly realized that all needs at all levels could not be served. Supplementary data other that than interpreted from remotely sensed data are needed for many applications. The information needs which could be met by using such sources were considered in total, and the related major land use and land cover types were logically divided into the Level I classes (deductive stage). Level II classes were created by considering which types of logical aggregations and subdivisions were possible using typical medium-to high-altitude aerial photographs. This process of inductive/deductive interation was carried through several cycles. USGS Circular 671 and Professional Paper 964 represent statements published at the completion of two of the cycles. New sensor capabilities and information needs are currently being assessed, in the latest cycle.

The USGS classification system, in this perspective, is the result of the combination of inductive processes (represented here by remotely sensed image interpretation capabilities) and deductive processes (logical division of the landscape as related to resource information needs). Since the system is capable of being extended to (or beginning at) more finite levels of classification, users (and classifiers) find that the inductive and deductive processes meet at the particular level in which the user has the most interest. In addition, he finds that he must venture into one level more finite than his principal interest in order to define what his classes contain. Thus, Level II definitions actually are described in terms of certain types of Level III classes. The need for such definition cannot be stated too strongly. In order to transmit information about his classes, the taxonomist must give the user of his classification ample definitional information, or the user can never replicate such classes or add compatible information to the system. Not only should he define what is the central theme of each class, but he should also describe the boundaries or limits of each class.

Similarly, the taxonomist must consider one more general level of classification in order to make certain that he has considered all possible criteria for subdividing the classes at the level of his interest.

Two processes are embodied in this discussion which should not be confused by the reader. The first is the process of devising a strategy to be pursued during the creation of a classification system. The second is the process of classification itself, the assigning of individual objects (or land parcels) to classes. Grigg (1965, p. 480) refers to the latter as "tactics." The strategy used (Nunnally and Witmer, 1970) is very important, since it represents the conceptual framework used in constructing a classification and ultimately determines its utility and acceptance.

We usually encounter no difficulty using our "tactics" when classifying land parcels that are very different and discontinuous. More typically, though, we encounter difficulties

where the diversity inherent in the landscape produces continuous variations in land use or land cover types because of differences in density, size, shape, pattern, etc., of criteria used in assigning parcels to classes. Of necessity, this requires the interpreter of the remotely sensed data to consider several criteria for each class simultaneously, and the taxonomist to create classifications (termed "polythetic") based on several criteria at each level. Only a few classifications have ever been based solely on one or a few criteria ("monothetic"). These have usually been based on a fundamental physical law, such as in the case of the periodic table of elements. As Sokal (1974, p. 1118) points out: "Classifications based on many properties will be general; they are unlikely to be optimal for any single purpose, but might be useful for a great variety of purposes." Sokal also points out that polythetic classifications are being increasingly adopted in various disciplines and that monothetic classifications are being rejected as more is learned about the objects being classified.

Using the USGS system, an image interpreter utilizes many criteria (shape, size, tone, texture, pattern, color, etc.) within a particular land parcel to identify and classify the parcel, thus relating the forms found on the image to their functions in the landscape. (See Avery, 1977, for a general discussion of image interpretation procedures and a discussion of the USGS classification system and nationwide mapping program.) It might be pointed out that one function of classification in general is to minimize the variance within classes created, and thus ensure that any information transmitted by naming the class represents the most coherent information possible. This is the same procedure, for example, that is followed in computer-assisted classification of digital Landsat data into land use or land cover classes. Similar land parcels are grouped together on the basis of their spectral responses, which in turn represent an aggregation of many charactistics of the land surface (soil type, moisture present, cover type, etc.) displayed as a discrete spectral level for each Landsat pixel.

APPLICATIONS OF THE CLASSIFICATION SYSTEM

For any government to be effective, no matter what the level or jurisdiction, it must have precise data on certain spatial patterns classified according to some logical system in order to carry out certain administrative functions (taxation, defense, resource management, hazard assessment, etc.). Many of these functions are directly or intimately related to land use and land cover patterns. Certain data summaries are available for large administrative units (see, for example, Frey, 1973) which have been constructed by synthesizing statistics gathered by various agencies by different means and for different purposes. Until recently, no summaries have been available for large administrative units, either Federal, regional, or State, which have as their conceptual framework the actual delineation of land use and land cover types on a parcel-by-parcel, or polygon basis, rather than a sampling framework. The USGS nationwide land use and land cover mapping and data compilation program is the first comprehensive system ever developed in the United States for the mapping, inventory, computer storage and retrieval, publication, and analysis of such data.

There is a wide gulf between the creation of a classification system and the derivation of operational specifications for putting such a system to use in a mapping or data compilation program. Specifications have been written (Loelkes, 1977) which delve into more definitional detail than does Professional Paper 964, as well as describing class boundaries, minimum densities of objects in certain classes, minimum mapping unit sizes, etc. These ensure the replicability and coherence of the data set derived by using the classification.

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The Role of National and International Coordination in Ecological Land Classification[1]

Ed B.Wiken[2]

Abstract.--Coordination, both in an informal and formal capacity, serves an important role in the development of integrated land surveys. This role is exemplified in many of the circumstances surrounding the ecological land classification approach. In the past, coordination provided the means to capitalize on experiences and achievements of national and international sources. Through the Canada Committee on Ecological Land Classification and its members, the continuance of coordination will encourage: the transfer of research and technology, cooperative action to problem solving, efficient allocation of financial resources, the standardization of methods, and an understanding of the work.

INTRODUCTION

Integrated surveys, such as Ecological Land Classification, have been conducted by independent organizations throughout the world for at least the last four decades. Current approaches to these surveys have to a large extent capitalized on their experiences. Consequently, while the actual work of individual organizations may have been confined by administrative boundaries, the impact of their work was not as restrictive. The knowledge gained by one organization typically transcends these boundaries and is absorbed by others. Common interests in these experiences makes it inevitable that coordination should play an important national and international role.

As many of the activities related to the Canada Committee on Ecological Land Classification (CCELC) are exemplary, they will be used to illustrate the functions which national and international coordination serve. The discussion centres on two main points: what the presence and the absence of coordination has meant to our approaches to integrated land survey in the past; and, what coordination will mean to survey work in the future.

[1]Paper contained in the Proceedings of a National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan. 8-12, 1978.

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HISTORICAL PERSPECTIVE

Hindsight indicates that integrated surveys have been tempered by nearly a century of theory and research, and over a quarter of a century of operational usage. Collectively, this tempering has been instrumental in shaping the basic philosophy and methodology which underpins integrated land surveys. When a national approach was sought in Canada a decade ago, these accumulated experiences proved invaluable. This material formed a substantial proportion of the platform from which the Canadian approach was launched. The international influence clearly continues to be mirrored in recent North American attempts to derive approaches to integrated land surveys.

International Influences

There is a long history of informal measures of coordination on an international basis. These include exchanges of information at the practitioner level via international journals, seminars, conferences, workshops and working groups. The effect of this cooperative exchange has been fairly universal and it continues to influence the development and implementation of integrated surveys. If the contributions to this field were not made available on the international market, it would be justifiable to conclude that the 'stone age' would have been re-entered in several countries. While more detailed summaries have been given (Christian, 1968), a capsular version will be illustrative of these international contributions.

Although there is no precipitous beginning, the initial precedents of general theory and practice were introduced in the late 19th century. As with most new fields of endeavor, V.V. Dokuchaev entered the arena to test ideas more central to his own concerns. In his 1898 doctrine of natural-historic zones, he expounded upon the unity and shared characteristics displayed by independent and territorially bound parcels of land (Isachenko, 1977). Further, as Kalesnik (1962) states, he "called for the study, not of individual bodies and natural phenomena, but of certain integral territorial aggregates of them". These notions remained central to succeeding ecological land classification studies.

Several authors followed these ideas when this field of study was first reaching for disciplinary status. Their works represented a series of hallmarks but few fundamental innovations, other than a hierarchical structure of generalizations were advanced. As figure 1 suggests, they mainly offered alternative versions to each others work. Each version was coloured by terms and complexities peculiar to the author's educational background. English works, such as Herbertson's (1905), followed the school of 'regionalism' and called for the study of 'natural regions'. Unstead (1916, 1933) summarized his contributions and expanded upon a hierarchical structure which included categories termed 'regions', 'tracts' and 'stows'. Other analogues were to parallel and to follow. In 1913, Passarge proposed and researched Germany's 'landscape science' (Troll, 1971) while Berg documented similar works in Russia. Veatch's efforts (1930, 1934, 1937) in Michigan outlined 'natural geographic divisions' and 'natural land types'. In surveys undertaken within the British Empires, Bourne (1931) derived his concepts of 'sites' and 'site regions'. Sukachev's investigations (Sukachev and Dylis, 1964; Shvarts and Gorchakovskii, 1973) into 'biogeocenology' established the avenue for biogeoclimatic zonation of the land. In Australia, Christian's and Stewart's (1957) concept of the land systems and the land units is another example of an alternative which has been given international exposure.

Besides subdividing and refining the fundamentals, these alternative schemes have yeilded an arsenal of terms. This proliferation of words has developed ambiguities. For example, from the categories used in the hierarchical systems alone (fig. 1), it is apparent that the same phenomena could be given different labels by different authors. Conversely, as with the 'land region' category, the same labels could refer to different kinds of phenomenon. As a result, it has been progressively difficult to correctly extract or sift information from documents published in other countries. While these ambiguities are frequently inconvenient, they have not ruled out the possibilities of international cooperation.

AN ATTEMPT TOWARDS INTERNATIONAL COORDINATION

In Australia, the Commonwealth Scientific Industrial Research Organization (CSIRO) through the Division of Land Research has developed an approach to ecological land survey. When the Working Group on Land Classification and Data Storage (Brink et al,1966) reviewed this approach along with systems orginating from other countries and organizations, they found numerous commonalities. The group concluded that the same principles and means of defining units of similar size and complexity were being used even though the respective terminology in cases differed because of their aims. In addition to the CSIRO approach, this conclusion was based mainly on the comparison of the works of: the National Institute for Road Research in South and Central Africa; the Oxford-Military Experimental Establishment in the United Kingdom; and the Directorate of Overseas Surveys in Africa. The results of their working group report attests in part to the universality of approaches to ecological surveys. Since the national approach in Canada is closely akin to these works, it provides further affirmation.

FORMULATION OF A NATIONAL APPROACH FOR CANADA

When guidelines were formulated, Canadian resource personnel were working on the initial phases of the Canada Land Inventory (CLI, 1970), an interpretive inventory providing land capability ratings for agriculture, forestry, wildlife (waterfowl and ungulates), recreation and sports fish. For much of Canada, the basic environmental data from which these interpretations were generated was either absent or only partially completed. To provide the data which was missing, a rapid and inexpensive approach to land survey was sought. In 1964, the National Committee on Forest Land (NCFL) established the Subcommittee on Biophysical Land Classification to explore possible alternatives. This interdisciplinary subcommittee drew upon the expertise which existed in various departments of provincial and federal governments, and, to a lesser extent, universities and private sectors. To derive guidelines, they held meetings, conducted workshops and carried out pilot projects in different parts of Canada. Through this process they were able to capitalize on existing international, national, and provincial benchmark studies. Relevant material was extracted and

Ref-erence	Name	APPROXIMATE MAP SCALES: (generalized) 1:30,000,000 — 1:15,000,000 — 1:10,000,000 — 1:5,000,000 — 1:3,000,000 — 1:2,000,000 — 1:1,000,000 — 1:500,000 — 1:250,000 — 1:125,000 — 1:80,000 — 1:50,000 — 1:20,000 — 1:10,000 — 1:1,000 — 1:500 (detailed)
1.	BIOPHYSICAL (English)	LAND ZONE · LAND REGION · LAND DISTRICT · LAND SYSTEM · LAND TYPE · LAND PHASE
2.	BIOPHYSICAL (French)	ZONE ECOLOGIQUE · REGION ECOLOGIQUE · DISTRICT ECOLOGIQUE · SYSTEM ECOLOGIQUE · TYPE ECOLOGIQUE · PHASE ECOLOGIQUE
3.	BIOPHYSICAL (B.C.)	BIOPHYSICAL REGION · BIOPHYSICAL SYSTEM · BIOPHYSICAL UNIT · BIOPHYSICAL COMPONENT
4.	HILLS	SITE REGION · LAND UNIT · LAND UNIT COMPONENT · PHYSIOGRAPHIC SITE TYPE · PHYSIOGRAPHIC ECO TYPE
5.	CROWLEY	DOMAIN · DIVISION · PROVINCE · SECTION · DISTRICT · LOCALITY · GEO ECOCATENA · GEO ECOSERE · PHYSIOGRAPHIC SITE PHASE
6.	CHRISTIAN & STEWART	LAND SYSTEM · LAND UNIT · LAND TYPE · SITE
7.	DOWNES & GIBBONS	LAND ZONE · LAND SYSTEM · LAND UNIT · LAND COMPONENT
8.	MEXE 872	RECURRENT LANDSCAPE PATTERN · FACET · SUB FACET · VARIANTS & LOCAL FORMS
9.	MEXE 940	LAND ZONE · LAND DIVISION · LAND PROVINCE · LAND REGION · LAND SYSTEM · LAND UNIT · LAND COMPONENT
10.	UNSTEAD	REGION · MINOR REGION · SUBREGION · TRACT · STOW
11.	BELGIUM	DOMAINE ECOLOGIQUE · SECTEUR ECOLOGIQUE · DISTRICT ECOLOGIQUE · STATION ECOLOGIQUE
12.	FRANCE	ZONE BIOGEOGRAPHIQUE · REGION ECOLOGIQUE · SECTEUR ECOLOGIQUE · SECTION ECOLOGIQUE · UNITE PHYTO-ECOLOGIQUE
13.	ECOCLASS	DIVISION · PROVINCE · SECTION · SUBSECTION · LAND TYPE ASSOCIATION · LAND TYPE · LAND TYPE PHASE · SITE
14.	VEATCH	NATURAL LAND DIVISIONS · LAND REGION · MAJOR DIVISIONS · LAND TYPE · MINOR UNIT
15.	SOVIET	UROCHISCHCHA · UROCHISCHE · SUB URUCHISCHA · FACIES · TOPO-ECOLOGICAL UNIT
16.	TROLL	LANDSHAFT MOSAIC · LANDSHAFT UNIT · LANDSHAFT ELEMENT
17.	WORLD LIFE ZONE	LIFE ZONE · ASSOCIATION · SUCCESSIONAL STAGE OF COVER TYPE
18.	FENNEMAN	PHYSIOGRAPHIC PROVINCE · PHYSIOGRAPHIC DISTRICT · TOPOGRAPHIC TYPE, NATURAL LAND TYPE, LANDSCAPE TYPE, TERRAIN TYPE

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Figure 1.--Hierarchical systems of approaches to ecological land classification.

a national approach was documented.

In 1969 the report, 'Guidelines for Biophysical Land Classification' (Subcom. on Biophy. Land Class., 1969) was proposed as a national approach. The report outlined a means to "differentiate and classify ecologically-significant segments of the land surface" as manifested by their inherent biological and physical land characteristics; and proposed a hierarchy of levels of generalization. The overall approach was to rely heavily on airphoto interpretation combined with supportive ground truthing.

The published guidelines were not intended to be conclusive. Rather, a first approximation was envisaged. Developments and modifications were anticipated with its continued use.

Since its publication, the guidelines has been employed in a variety of environmental studies beyond those related to the Canada Land Inventory program. It has been given tangible approval as a consequence of over 60 studies which have been conducted or are underway in Canada. These studies have been associated with different departments of both federal and provincial governments, and private consulting firms. The larger area studies are shown in figure 2. Invariably, these have been limited to non-cultural landscapes where environmental baseline information has been incomplete or lacking. The total area surveyed approaches 5,600,000 km^2.

The particular survey organizations which have been responsible for these studies have differed substantially in their mandates, purposes, and capital and personnel resources. Because of these disparaties, the developments and modifications of the original guidelines were weighted. In addition, the changes which were generated have not always been paralleled or synchronized with those generated by other organizations. Unfortunately, the Subcommittee on Biophysical Land Classification was disbanded in 1972. The lack of a coordinating committee removed a specific national forum in which these individual changes could be profitably discussed. This vacuum also isolated many organizations. Progress on these guidelines consequently evolved in a regional or provincial context rather than a national one. It is understandable then that organizations were not all attuned to what specific changes had taken place. As a result, what was meant by the national guidelines was no longer clear and was difficult to define as a single unit.

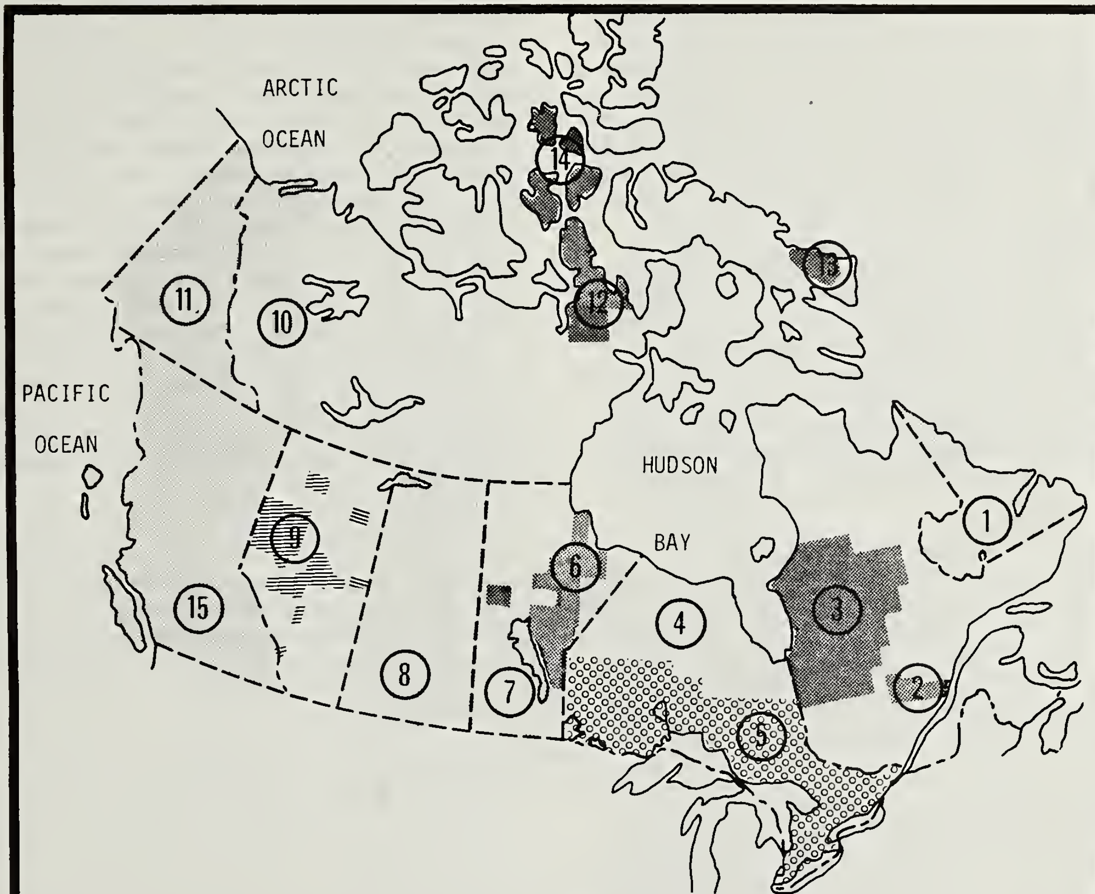
With the mixed concepts surrounding the biophysical land classification approach and the growing interest in integrated land surveys, it was clear that a national coordination committee, similar to the Canada Soil Survey Committee, was required. Recommendations to this extent were made at the Canada Northlands workshop which was convened in Toronto (Lands Directorate, 1974). Representatives from federal and provincial governments, universities and consulting firms recommended that this committee should amass guidelines for integrated surveys, standardize methods and terminology, and coordinate approaches nationally, provincially and regionally.

A small ad hoc committee representing the Lands Directorate of Environment Canada, the Soil Research Institute of Agriculture Canada, the Terrain Sciences Division of Energy, Mines and Resources, and the Water, Lands, Forests and Environment Branch of Indian Affairs and Northern Development in cooperation with the provinces organized, in 1976, a meeting in Petawawa. From this, the Canada Committee on Ecological Land Classification was founded. Ecological land classification refers to an integrated approach to land survey in which areas of land, as ecosystems, are classified according to their ecological unity (Wiken and Ironside, 1977). This approach to land survey was originally designated 'Biophysical Land Classification'; however, in accordance with the recommendations of the Petawawa meeting the term Ecological Land Classification was adopted. As an interim measure, 'Biophysical' was retained in parenthesis after 'Ecological'.

CANADA COMMITTEE ON ECOLOGICAL LAND CLASSIFICATION

At the first national meeting of the CCELC, a series of papers dealing with ecological land classification were presented. This updated the participants of the meeting in relation to the present philosophies, methodologies and applications of the approach. Following the papers, the terms of reference, organization, membership, activities and working groups were decided by the participants.

The primary objective of the CCELC is (CCELC, 1977) "to encourage the continued development and to promote the application of a uniform ecological (biophysical) approach to land classification for resource planning, management and environmental impact assessment purposes". This objective will be achieved through several activities of the CCELC, including: the exchange of technical and general information; the organization of problem orientated working groups and workshops; the initiation of dialogue with current or potential users of ecological land classification type surveys; and the encouragement of



1. Labrador
   Lands Directorate,Atlantic Region
2. Saguenay-Lac St. Jean
   Ser.Des Etudes Ecologiques Regionales
3. James Bay
   Ser. Des Etudes Ecologiques Regionales
4. Ontario
   Ontario Land Inventory
5. Southern Ontario
   Ontario Land Inventory
6. Northern Manitoba
   Canada- Manitoba Soil Survey
7. Manitoba
   Canada- Manitoba Soil Survey
8. Saskatchewan
   Canada Land Inventory
9. Alberta
   Land Use Assignment Committee
10. Mackenzie Valley
    Indian Affairs and Northern Dev
11. Yukon
    Canadian Forest Service
12. Boothia Peninsula
    Canada Soil Survey
13. Auyuittuq
    Parks Canada
14. Arctic Islands
    Canadian Forest Service
15. British Columbia
    University of B.C.

Figure 1.--Location of major studies in ecological land classification.

recommendations and advice to governmental and private agencies on the application, benefits and costs of integrated land surveys.

The CCELC emerged, largely, as a result of personal contact between practitioners. As such, its coordinating capacity is predominantly an informal one. The coordination function is oriented towards a catalytic role, centring on those aspects of ecological land classification which have particular significance to the membership. The general organizational structure is shown in figure 3. This is an open structure designed to encourage interaction and feedback between its components. The Lands Directorate in Ottawa supports the committee by providing a secretariat and publishing newsletters and documents of the CCELC. Upon request, representatives to the committee have been designated by federal and provincial departments, particularly those having interests in integrated surveys. Representatives also included specialists from universities and government organizations. Finally, the structure involves five working groups: Methodology/Philosophy, Applications, Data Systems, Wetland Classification and Land/Water Integration. Each group was formed in response to recommendations of committee members. The membership of each group is responsible for cooperatively tackling specific problems or documenting particular gains in ecological land classification. Due to the large interest, frequently in the order of hundreds, the respective working groups have been forced to work with a small immediate group and to correspond with interested individueals through the CCELC mailing list. Through this process each group has the capacity to solicit and to give advice provincially, nationally and internationally.

The committee has operated for nearly two years. Based on past progress and future potentials, there is a rationale for the committees continued involvement in a coordinating capacity.

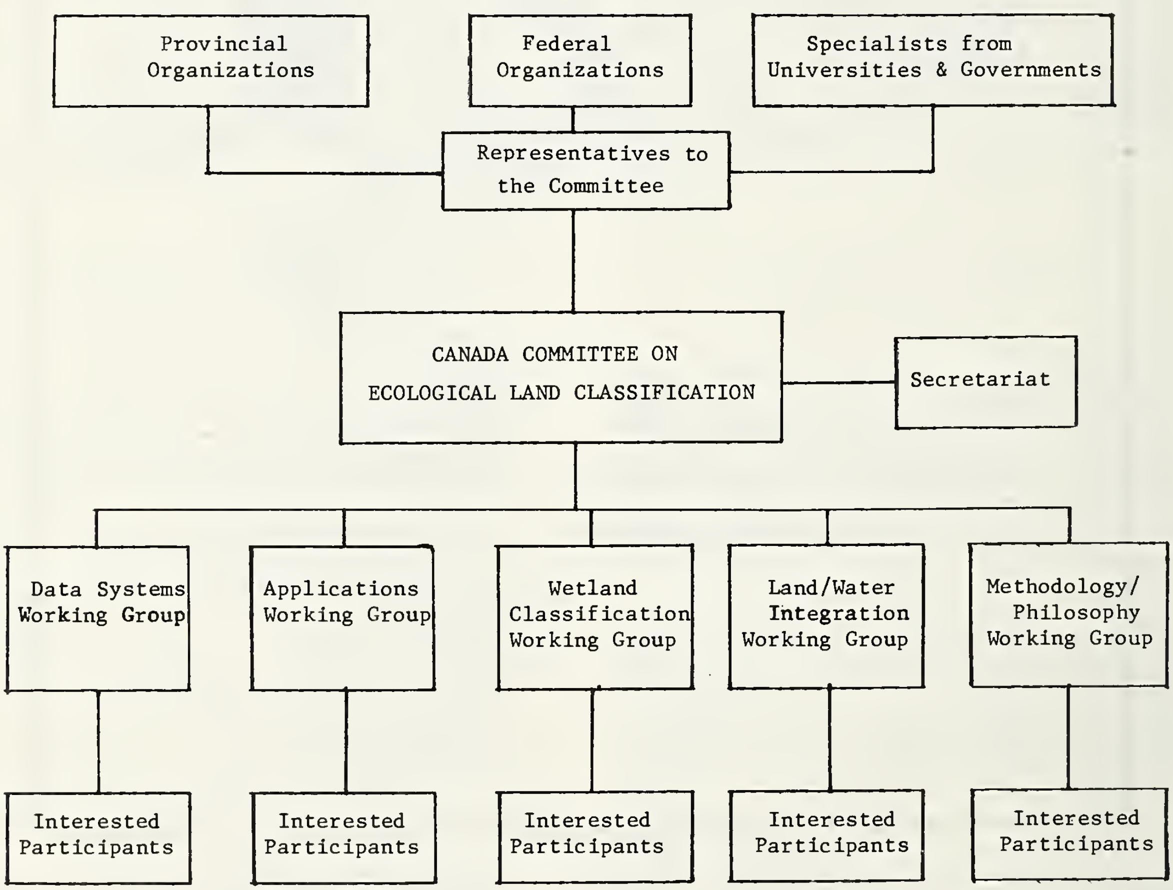


Figure 3.--General organizational structure of the Canada Committee on Ecological Land Classification

RATIONALE FOR FUTURE COORDINATION

It is difficult to quantify what is returned for investing in activities pertaining to national or international coordination. The value for such activities always tends to be implicit from the pieces of work which emanate from a given situation. If an accounting system was readily applicable to the work of the CCELC, a value would certainly be assigned to the enterprises which encourage: an understanding of the field, the transfer of science and research, the cooperative action to problem solving, the efficient allocation of financial resources, and the standardization of methodologies and terms.

Encouraging an Understanding of the Field.--Cultivating an understanding of the field between workers at all levels of government and business is one of the less tangible benefits of coordination. However, cooperative participation in workshops, working groups and general information exchange allows workers in the provinces to obtain a greater national perspective of their work. Equally for the workers at the federal levels, it permits a means to secure a greater understanding of provincial and regional concerns. From both standpoints, encouraging an understanding increases the consciousness and appreciation of matters related to the field of ecological land classification. Similar relationships hold at the international level.

Encouraging the Transfer of Science and Research.--The exchange of science and research is mutually rewarding. Methods and techniques developed by one organization are often transferable to other provinces or nations. This is especially pertinent where integrated land surveys deal with similar kinds of environments and purposes. The Alaska-Yukon pipeline route is one such example. By cooperatively exchanging the findings of science and research, organizations are better apt to be guided by comprehensive and current information. In doing so, they ensure the most beneficial and efficient use and management of the resources at their disposal.

There are definite scales of economies attached to the transfer of science and research. By engaging in a collective strategy in this domain, savings could be accrued.

Maintaining scientific expertise and research capabilities involves the expenditure of human and nonhuman resources. Economies are gained depending on how these resources are deployed. When the direction of research and the complement of scientific expertise of an organization are not known, the chances for duplication and overlap of pursuits are increased. A forum for detailing technical aspects which organizations have been or are engaged in would reduce expenditures geared to re-inventing the same wheel. Consequently, scientists could devlop their research in a complimentary or corroborative fashion rather than a repetitive one. For those organizations which lack particular types of expertise or research, a forum which coordinates the transfer of science and research also means pay-offs in another dimension. It affords these particular organizations with the opportunity to gain from advances which would normally be beyond their individual capacities to acquire.

Encouraging Cooperative Problem Solving.--Just as sharing the results of science and research can be mutually beneficial, so can the cooperative action to problem solving. This action of course hinges on a willingness of individuals or organizations to cooperate. It would be quite unrealistic to expect otherwise when there are no formal agreements which bind participants to the CCELC. A motivation to participate is self-cultured because common and shared goals are pursued.

In instances, integrated surveys possess problems which by their very nature are either broad in their scope or beyond the capability of any one organization or individual. Because of the wide interest in such matters, a collective action for solution is required. Documenting the philosophy underlying ecological land classification is a prime example. In the initial guidelines of 1969, it was unclear or buried in several reference documents. From a national perspective, it remained so until 1977. The Working Group on Philosophy/Methodology has achieved greater and quicker degrees of success in that one year than what was achieved in the past 8 years. Positive results of concerted actions are not limited to this working group. They are typical of what has been achieved by other working groups as well as the problem oriented workshops of the CCELC. Examples are contained in the reports on Land/Water Integration (1977) and Ecological Land Classification in Urban Areas (CCELC, 1977).

Encouraging the Efficient Allocation of Financial Resources.-- The wise use and management of public or private funds can be encouraged by cooperatively pooling and advertising the merits of an integrated approach to land survey. Money is required to support human and nonhuman resources in the execution of surveys. The efficiency in dispensing this money can be measured by the amount of resources allocated to produce a desired unit of output.

The needs of planners and managers are becoming increasingly diverse. To be appropriate, the results of a survey must be versatile. It must be capable of evaluating current

or expected land uses practises by identifying: the thresholds and limits of land ecosystems, the range of management strategies available, the environmental impact of proposals by indicating the degree of compatibilitiy with the land ecosystem, the significance of new technologies, the low risk alternatives, the opportunities for renovation and sequential land occupation, etc.. To meet these embracing evaluations calls for an equally holistic view of the natural environment. The broad descriptive data base of the ecological land classification approach is consonant with these requirements. Also, the emphasis of documenting the more stable land characteristics maintains the data base's utility in the long term.

An integrated approach to land survey has numerous cost advantages over interpretive surveys or a comparable number of single disciplinary studies. The Canada Land Inventory, an interpretive land capability inventory for 6 resource sectors, cost about $\$14/km^2$. Maps were produced predominantly at a scale of 1:250,000. In contrast, the integrated land survey for the James Bay Development cost approximately $\$12/km^2$. Maps were produced largely at the mapping scale of 1:125,000. Approximately 34 interpretations have thus far been produced from the ecological data base. The higher cost of the single disciplinary program, even though it was less detailed, is related to redundancies in several areas: transportation, field work, support staff, cartographic map production and computer data handling.

Encouraging the Standardization of Methodologies and Terms.--The responsibility for gathering land resource information is shared amongst levels of government and private enterprise. Because of this jurisdictional division and because coordination between these levels is lacking, the approaches taken can be disparate. As a consequence of the different methods and terms employed, the data bases which eventuate from particular approaches are frequently incompatible or unwieldy in relation to each other. When this common denominator between data bases is absent, it is difficult for planners and managers to coherently resolve environmental matters which are cross or jointly jurisdictional. National and international agreements concerning wildlife and migratory bird habitats, and water management are some of the more obvious examples. Through coordination, mutually acceptable methods and terms can be established and a common platform for dialogue can be initiated.

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Techniques Developed and Presently Being Used to Conduct the National Wetlands Inventory Project[1]

John H. Montanari and Bill O. Wilen[2]

Abstract.--The National Wetlands Inventory Project has attempted to use existing data, systems and techniques when they met the Project's goals and objectives. When they did not, new systems and techniques were developed to meet not only the Project's present but also its future goals and objectives.

INTRODUCTION

The need to consider and use sound ecological information in forming decisions concerning policy, planning and operational management of our natural resources is a well-known concept of long standing. This concept has been the subject of significant laws, including the Fish and Wildlife Coordination Act of 1934 as amended, the Endangered Species Acts of 1966 and 1969, the U.S. Forest Service's Multiple Use Act of 1960, the Forest and Rangeland Renewable Resources Planning Act of 1974, the Marine Mammal Protection Act of 1972, the National Environmental Policy Act of 1969, and, of major significance to this Project, the Federal Water Pollution Control Act Amendments of 1977.

As state and federal agencies implement programs of wetland management and regulation, it is essential to know the location and extent of the wetland resource. Agencies which are involved in permit programs are by and large operating on a case-by-case basis determining whether individual wetlands are affected by proposed actions and assessing the significance of proposed alterations. In the absence of wetland maps and other wetland data, it is difficult to establish priority levels or screening processes to insure optimum use of dollars and over-all effort in the permit application and review process. Maximum attention cannot be achieved in important cases if resources have been drained away on other cases. A sound wetlands inventory is a requisite to establishing priority and significance levels, and efficient use of time and money.

Without the inventory information decisions are rendered in a partial vacuum. The vacuum effect occurs because decisions on individual wetland sites are made without reference to the location and role of the site in the relevant wetland system. Wetlands are an example of Barry Commoner's observation that "Everything is connected to everything else," yet agencies continue to make decisions in partial vacuums because they don't know where the related elements of the resource are, and how they connect. Wetland maps and data base information provide the missing perspective and are the basic foundation on which to form policies to regulate piecemeal alteration of large wetlands and wetland systems.

Public management and regulation of the wetland resource is a process in which all participants require full disclosure. Wetland maps provide the necessary public notice that an overriding public concern exists and that regulatory procedures are to be anticipated if alteration is proposed. Wetland maps function in a manner similar to that of flood hazard, zoning and soil interpretation maps. Acceptance of state and federal wetland

[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan. 8-12, 1978.

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management programs is greatly facilitated by public disclosure via mapping. Individuals and agencies can be said to have an inherent right to know the location and dimension of the wetland resource if they are to cooperate with wetland management programs. I suspect that this right can be successfully established in court.

Consequently, we have tried to design the National Wetlands Inventory so that it will provide a single, universally applicable system of wetland information which will describe all wetlands on an individual and/or cumulative basis in terms of their ecological and physical characteristics, geographic location and natural resource values. Further, we will use this endeavor to provide a base and guide for the development of an all-habitat-inclusive system designed to include classification, ecological characterization (Hirsch, 1976), geographic location and evaluatory information needed in natural resource policy formulation, planning and operational management.

The last national wetland inventory, which surveyed only the lower 48 states, was completed in 1954 (S.P. Shaw and C.G. Predine, 1956). Since the 1954 inventory, a large amount of wetlands modification has occurred. In addition, the importance of wetlands in the biological and physical environment is more widely appreciated, and a better methodology exists for classifying and inventorying this resource.

THE NEED FOR WETLANDS INVENTORY DATA

At the federal level alone, there are at least 10 groups within the Department of Interior, as well as nine other federal agencies (including Corps of Engineers, Environmental Protection Agency, and National Marine Fisheries Service) which have indicated a need for the data to be produced by the National Wetland Inventory (NWI). A wide range of regional, state and local governmental bodies, and private conservation groups have stated specific needs to apply this data to their own programs.

Within the Fish and Wildlife Service, there are three major uses of wetlands inventory data:

1. The Fish and Wildlife Service (FWS) is currently required to process approximately 35,000 permit applications per year for activities using wetlands.

2. Each year a considerable amount of money is authorized for the migratory bird wetland acquisition program. The NWI products will assist in the identification of critical areas in order that priorities for wetland acquisition can be established.

3. The federal-state cooperative migratory bird management program requires a continuing qualitative and quantitative analysis of wetland habitat. The National Wetland Inventory will provide an accurate, comprehensive data base for this analysis.

GOALS AND LONG TERM OBJECTIVES

. Provide needed information that will aid the FWS, other interested agencies (state as well as federal), private organizations and individuals to achieve resource management and habitat preservation objectives.

. Develop an inventory system that can be easily and economically maintained.

. Develop the system and gather the basic informational needs in as short a period of time as is technically and economically feasible.

. Present the information in a variety of products to insure its maximum usefulness to the user (maps, data bank, reports, and work materials).

PRE-OPERATIONAL PRODUCTS

The NWI project has now completed its pre-operational stage. Five major pre-operational products are completed. They are described as follows.

A New Wetland Classification System

The system used in the 1954 inventory identified 20 wetland types, all of equal rank. Other existing wetland classification systems use a similar "horizontal" system. The classification system developed for the NWI is hierarchical or vertical in nature. The uppermost levels are broad systems (marine, estuarine, riverine, lacustrine, palustrine) and the hierarchy proceeds through several decreasing levels, ending with highly detailed and specific wetlands characteristics.

There are several advantages to this "vertical" structure, the principal one being the ability to utilize the classification system to levels of detail as required by the individual user. Thus, while local governments or agencies may wish to describe wetlands in detailed fashion, state or regional agencies may desire a general description.

There may be some concern that the classification system needs to be "perfected" before the inventory can get underway. From our knowledge of classification systems on this continent and from visits with colleagues in Europe, we believe that this system represents

the state of the art. The unresolved questions in the system are not critical faults. We know of no taxonomic system which is not subject to review, amendment and fine tuning or even major alteration (soils), all of which are accomplished without impairing the service function of the systems or the agency employing them.

The system as developed and tested today represents an advancement of a magnitude which fully justifies it as the basis for a new national inventory. Unlike the Circular 39 inventory, whose basis was focused on a limited function of the wetland (duck habitat), this classification is based on measurable physical features and gives rise to inventory and identification of values and functions of interest to a wide array of users.

A Survey of Existing Wetland Inventories

This survey compiles information on wetland inventories conducted by federal, state and local governments, and private conservation groups since 1965. The NWI will utilize these inventories to avoid duplication of efforts. This survey will also be of immediate value to other agencies that wish to locate inventories of specific areas.

The Survey is published in two volumes. Volume I, representing each of the six FWS regions, contains 1:750,000 state maps showing the location and extent of major wetland inventories. There are six issues of this volume, one for each of the six FWS regions. Volume II contains a narrative description, by state, of all known inventories since 1965. Included in the narrative description is inventory information such as the classification system used, the purpose of the inventory, the methods used, the legislation involved, and how an interested user may obtain additional information concerning a particular wetland study.

An Atlas of Recent, High Altitude Aerial Photography

The NWI will use, in part, aerial photographic interpretation techniques to inventory the wetlands of the United States. Compilation of a graphical index of existing, high-quality aerial photography was a necessary step in order to locate the imagery needed to conduct the inventory.

The Atlas displays on 1:750,000 state maps recent aerial photography (since 1970) subject to specific parameters based on the requirements of the NWI. These parameters are:

- Scales of 1:40,000-1:130,000;
- Only blocks of imagery covering at least 50 sq.mi.;
- Exceptionally high quality;
- Preference is shown in order for color infrared, color, black and white infrared, and black and white film emulsion types.

A Series of 1:250,000 Maps Delineating Ecoregions, Physical Subdivisions and Land Surface Forms of the United States

This series of 468 maps, covering the conterminous 48 states, displays the boundaries and ecoregions (Bailey, 1976) and physical subdivisions (Hammond, 1964) on standard 1:250,000 USGS map sheets. Alaska, Hawaii and U.S. possessions will be completed during fiscal year 1978.

Wetland Protection Guidebooks For Use By Local Units of Government, States, and Interested Citizens

Existing state and local wetland protection efforts have been digested and alternative model statutes and ordinances drafted. Two guidebooks were prepared. One is a scientific and legal handbook detailing technical planning issues (including wetland inventories), legal issues, and regulatory and non-regulatory approaches in wetlands protection.

A second guidebook, specifically for local units of government, presents model ordinances and a step-by-step approach in adopting local wetlands regulations.

OPERATIONAL PRODUCTS

The operational phase of the NWI was initiated in October, 1977, and is scheduled for completion in 1981. The inventory system and products are designed so that they can be continuously monitored or periodically updated. The current status of wetland modification or loss may be monitored and recorded in the future.

The major products include the following.

The National Wetland Inventory Map Series

These maps display wetlands, classified according to the system described in the pre-operational products section, at a scale of 1:100,000 for the entire United States. Acreage of each wetland will also be displayed. In areas congested with a large number of small wetlands, as in the Florida karst terrain or the prairie pothole region of the Dakotas, maps of 1:24,000 scale will also be produced provided additional funds are made available for production

of these large scale maps.

The maps will be useful in the implementation of statutory and regulatory responsibilities. Federal and state agencies have been invested with statutory and regulatory responsibilities over the wetland resource by legislative action designed to protect and insure continued public values and functions of wetlands. The maps and the classification system support both of these responsibilities in a step-wise fashion:

. Statutory - The maps could serve at this level as locators of wetlands and the classification system as the definition of wetlands for every mapped wetland. Language of the statutes should refer to the maps as locational instruments and should confer upon the agency the power to make regulations to refine the wetland boundaries.

. Regulatory - Agency regulations could provide that where the developer and the regulatory agency agree, the boundaries on the maps may stand as the wetland boundary with regard to wetland regulation. They should further provide that where agreement cannot be reached, the boundary will be determined in the field employing the criteria set forth in the classification system. (A usual technique is to provide that this additional cost be borne by the developer.)

A National Wetland Inventory Data Bank

All information gathered for each wetland, as displayed on the map series, will be digitized and placed in a geo-based Data Management System. Each wetland will be located by latitude and longitude, physical subdivision, ecoregion, hydrologic unit, state and county. This information can be retrieved and manipulated to produce either tabulated printout sheets or computer generated maps.

As an example, wetland data generated by the computer program will be to National Map Accuracy Standards at 1:24,000 or smaller scales.

Regional and National Summary Reports

These reports will summarize the findings of the inventory in each state, FWS region, and for the entire country. They will include tabulations of data for wetland type, political division, flyway and natural physical division (such as land surface form, and watershed).

Work Materials

While conducting the inventory, a vast amount of collateral data, aerial photography, compilation maps, work sheets and field reports will be collected. These materials will, if possible, be made available on a limited basis to those organizations which have a need for it.

NWI IMPLEMENTATION STRATEGY

Several criteria were fundamental to development of NWI strategy:

. The need to qualitively standardize the results of the inventory across the country;

. The need to establish a system of management control for a project of this magnitude;

. The need to establish a system that maximizes the efficient use of fiscal resources;

. The need to develop inventory products that meet the needs of the largest number of potential users.

The central NWI operational group is the focal point for coordinating all activities concerning the inventory. This group, located in St. Petersburg, Florida acquires all work materials necessary for performing the inventory, has developed a set of guidelines (operations manual), and provides technical assistance and guidance, as well as the work materials, to seven Regional Wetland Coordinators (one established in each of the six FWS Regional Offices, plus Alaska).

The regional coordinators are responsible for the inventory of wetlands within their region and the preparation of regional reports.

The collection of inventory data is accomplished by contract with either state organizations or private contractors. Contractors are directly responsible to the regional coordinator. They use the work materials supplied by the central office, inventory wetlands as directed, and provide the regional coordinator with completed field check site reports (summary reports and delineated photographs).

When geographic areas have been satisfactorily completed, the work materials are forwarded to the central office where the materials are edited and the final products completed and made ready for distribution to users.

The operational strategy also provides that other "interested" federal agencies would be invited to participate, at their own expense, in the operation of the central office. Although this is not critical to the operation of this facility, it accomplishes several things. First, it facilitates the collation of existing collateral data that exist within other federal agencies. Second, it expands levels and scope of expertise, i.e., soils, hydrology, etc. Third, it provides

an interchange of ideas and a means for operational level, interagency coordination and dissemination of information.

EQUIPMENT AND SYSTEMS DEVELOPMENT

Standard procedures for transferring topical information such as wetland data from a single photograph to a map results in the information being located at a lower level of accuracy than the accuracy of the map base. These locational inaccuracies led to problems of overlap when adding information on areas adjacent to wetlands and would make updating with satellite imagery difficult. While current technology in digitizing and computer storage of data is well developed, technology for locational accuracy that makes such products useful has not been fully developed. For this reason, NWI personnel looked into a number of data reduction and data base generation systems in hope of finding an existing system or equipment which would allow NWI to both solve the locational accuracy problem and to input wetland data into a geo-based management system. There were several considerations which led to this decision.

The first consideration was whether or not stereoscopic photo interpretation was necessary. It was decided, because of the nature of wetlands, that stereo interpretation was extremely desirable.

The second consideration was whether to use stereoscopic compilation techniques or standard X, Y digitizing directly from aerial photographs or photo enlargements.

Standard X and Y digitizing of photographs, flown under strict specifications, for areas of the country in which relief is insignificant, provides sufficient accuracy for some applications. However, unless certain analytical transformations are performed, locational inaccuracies and the problem of edge matching information on adjoining photographs will plague the mapping operation.

For example, even on level ground at the latitude of Central Florida, the positional displacement at the outer edge of a 9" x 9" aerial photograph taken with a camera with a 6 inch focal length from 40,000 feet would be approximately 20 feet.

Where relief is a factor, the problem is additionally complicated. Errors due to relief, using the focal length and flying height mentioned above, are approximately 3/4 the relief of the model and this error is compounded since it works in opposite directions on adjacent photographs.

It was decided by NWI personnel that a photogrammetric compilation procedure must be practiced in order to obtain the required output accuracy. The technique of using stereophotographs to identify wetlands and having the photointerpreter transfer the locations of wetlands to orthophoto quads by relating photo detail was considered and dropped as a primary avenue of approach because of the lack of ortho photo coverage for the United States. This technique may still be used where ortho photos are available. Once the wetlands detail was transferred, this detail could be digitized off the ortho photo, using a standard X, Y digitizer.

The next obvious solution is to use rectified photographs in place of the ortho photos and go through the same interpretation techniques and transfer of the wetland detail; however, the cost is prohibitive, and the method does not solve the problem of displacement due to relief.

It became apparent that a photogrammetric compilation procedure must be practiced in order to assure the necessary output accuracies in all instances.

Photogrammetric plotters fall essentially into two categories. The first of these is the optomechanical plotter, which reconstructs the position of the photographs by optical and mechanical trains. All these plotters suffer from the restriction that the operator must be skilled in reconstruction of the photogrammetric model.

The second is the only class of stereoplotters which can be operated by a person not skilled in the orientation of photogrammetric models, generally referred to as "analytical plotters." For these plotters, the photogrammetric model is created mathematically by an on-line calculator or computer. Currently, there are two classes of analytical plotters commercial available which fit this description.

The first is a very high precision, first order analytical plotter that costs in the range of $100,000 to $200,000. Most of these plotters come with packaged computer programs. It is unrealistic to believe that any given user would not need additional software development. Some types of editing problems have been addressed and solved but many of the problems faced by the NWI were not addressed.

NWI personnel searched for a means of generating the required output accuracy for the inventory within budget limitations. The search uncovered the Analytical Photogrammetric Plotting System (APPS-I) developed to meet the U.S. Department of Defense's needs for a photogrammetric positioning system to support its surface-to-surface missile system. It was

further tested by the Army for use by Cannon Field Artillery Units, by the U.S. Navy for use in calculating Offset Air-point Bombing, by the U.S. Air Force for the location and exploitation of deployable point positioning data bases and by the Defense Mapping Agency.

The APPS-I as it was developed for the military is a point-to-point system. To be of use to the NWI it had to be converted to a "digitizing" system. It was estimated by NWI personnel that, if the APPS-I system could be converted from its military application to use by the NWI, wetlands and all other natural resources and land use topical information could be, for the first time, located within National Map Accuracy Standards and on a par with existing digitizing capabilities.

Although the recognition of the need and the possibility of the conversion of the APPS-I system was generated in-house, there was no in-house capability to make the hardware and software modifications necessary to convert APPS-I from its military application to use by the NWI. The first effort was simply an attempt to see if the conversion was possible. This conversion meant that the Hewlett Packard 9810 calculator had to be replaced with a HP 9830 B for increased computational power. Software had to be written for a single photo resection to solve for a photograph's orientation parameters, and a two-ray intersection to arrive at gound point coordinates.

The HP 9830 calculator had to be interfaced with a magnetic cassette tape digital recording system to store the results of the resection solution until it was needed for data manipulation. A HP desk top electronic plotter was added to allow the photointerpretor/biologist to maintain a surveillance of his mapping progress. The final modification was to convert the system from a paper tape to a magnetic tape recording system.

At this point the name of APPS was changed to WAMS, Wetlands Analytical Mapping System. The reason for the change was the confusion caused in the minds of the people who were familiar with the military version of APPS. The name APPS no longer represented the system developed for use by the NWI.

The major hardware modification between what has come to be called WAMS I and WAMS II was a change to a larger plotter. This plotter change required writing additional software. At this time, a new and expanded plot software package was added to allow the plotting scale to be interchangeable between 1:24,000 and 1:100,000, as was software to allow plot registration and location.

In September, 1976 the positional plotting accuracy of WAMS II was demonstrated. In its WAMS II configuration, the system was capable of locating and plotting wetlands to within National Map Accuracy Standards.

Operators were trained and WAMS was put into production mode in October, 1976. This effort uncovered some of the equipment, software and operational procedural problems. These problems were solved as they were encountered. It became apparent in late November that the existing equipment (HP 9830 B) was "compute bound." All attempts to alleviate this situation failed. Operation of WAMS II was stopped.

At this point, a growing belief by NWI personnel that Project requirements and goals would exceed the capacity of any known calculator, was confirmed. Long before the halting of the production of maps by WAMS II in early December, 1976, a third generation of WAMS was being discussed.

The present WAMS III system which has now been developed, increased accuracy by changing from a 1/1000 of an inch data grid to encoders with a resolution of 4/10,000 of an inch. The most important system change is the conversion from a calculator to a mini-computer (HP 2100 MXE) which increases the speed and efficiency of the system by about 500 times. The system is no longer "compute bound."

In summary, the reason for the development of WAMS is so that it can record the latitude and longitude of the data points and the wetland information can be changed to any required map scale and map projection. This frees the NWI from a static map base which will some day be out of date. When metric maps are produced, the latitude and longitude data can be converted to universal transverse mercator and replotted on the new maps. The level of accuracy of the data will make it feasible to add adjacent upland information to the NWI data base and at some date in the future to update the Inventory by satellite. The economical maintenance of the inventory lies in updating through the use of imaging satellites. The feasibility of this type of update is now being actively pursued. It is felt that the accuracy being generated will meet many protection and management objectives. Although the WAMS system has a heavy financial burden of equipment rental, it is felt that the system will be cost effective.

LOOKING FORWARD TO WETLAND EVALUATION

The classification and inventory process is grounded in measurable physical features and has avoided functional and qualitative descriptors. Continued adherance to this approach is

the best insurance that the entire program will form a sound basis for wetland evaluation.

The contribution and extension of the inventory into the evaluation phase will vary among values:

Flood Control

The significant contribution of the Inventory will be a display of the pattern of wetland types as they occur over the different types of watersheds. This pattern of wetlands on watersheds will be important in stimulating and designing the badly needed hydrologic documentation of wetland/flood relationships.

Groundwater

The contribution of the inventory in this value area is specific. It will allow superimposition of wetland patterns over surficial geologic mapping to determine the relationship of wetlands to potential groundwater acquifiers. This has been done in the northeast but needs to be done in the remainder of the country.

Coastal Storm Damage Protection

The Inventory will locate the coastal wetlands and permit specific study of the relationship between degree of coastal storm damage and the presence or alteration of protective wetland barriers.

Wildlife

Wildlife values of inland wetlands in relatively stable water regimes are based on vegetative-water patterns and plant life form. The classification and inventory activity makes it possible to develop for the remainder of the country wetland evaluation models such as that designed for the northeast. Wildlife values of inland waters subject to seasonal drawdown are tied to patterns of vegetation and life form but also to the regular release and availability of nutrients due to the drawdown process - a condition similar to that found in tidal wetlands.

Wildlife values of tidal wetlands are related more to the release and availability of nutrients than to the relatively homogenous plant community. Vegetative pattern and life form is less important here and soil water regime and water chemistry factors are likely to be key factors. Where these are enclosed in the inventory they will have an important and direct contribution to evaluation.

Shellfish, Finfish and Tertiary Waste Treatment

These values, including aquaculture, are keyed to nutrient availability and water chemistry. In general, the Inventory will provide the basis for evaluation in these areas by including water, soils and bottom type descriptors.

It will be most important to apply the entire classification system to tidal, seasonal drawdown and potential tertiary waste treatment wetlands in order to complete the link to these economically important values.

SUMMARY

The National Wetland Inventory Project has attempted to use existing data, information and techniques that meet the objective and goals established for the Project.

If new systems or techniques have had to be developed this has been accomplished, to the best of our ability, to meet not only the Project objectives but also the future needs of those that may have a more all encompassing need for gathering, displaying and distributing resource information.

Shrubland Classification in the Central Rocky Mountains and Colorado Plateau[1]

Scott L. Ellis[2]

Selection of appropriate vegetation categories is essential for efficient and accurate supervised LANDSAT multispectral computer classifications. Shrubland Communities of the western United States present a classification challenge because of their heterogeneity. A systematic separation of spectral classes found in the ground truth data (large scale CIR aerial photography) and stratification of training fields by soil, vegetation density, and slope and aspect was found to be a useful procedure in separating heterogeneous shrubland communities.

INTRODUCTION

Land cover classifications using multispectral digitized satellite data are commonly formulated through "supervised" or "cluster analysis" techniques. "One difference between "supervised" and cluster analysis" approaches is that, in the former, ground truthing takes place first so that the computer can be "trained" to recognize a land cover condition elsewhere; whereas in the latter, classification takes place first and then a ground truthing operation is launched to determine the land cover condition that corresponds to each resulting class." (Joyce 1977).

"The supervised technique requires that the location of a number of sites on which the land cover is known (e.g. a soybean field) be established in the LANDSAT data. These areas which are selected to contain a uniform, homogeneous land cover (e.g. a soybean field that is uniform in respect to planting date, density, vigor, etc.) are called "training sample sites", because, in a simplistic sense, they are used as references to "train" the computer to recognize the same land cover elsewhere" (Joyce 1977).

The classification process is critical to the successful outcome of a computer mapping effort because it must embody the objectives of the classification itself (i.e. the map product should convey the type of information that is desired); it must consist of categories that are amenable to consistent separation; and the number of categories must be consistent with the capability of data processing equipment.

A common problem in supervised classifications is that the classifier defines inappropriate cover classes because of a priori assumptions about the organization of the land cover that are incompatible with computer analysis or selection of adequate training areas. A second problem is that training sites within a class do not adequately characterize the class, resulting in mis-classification and uncategorized areas. This situation is being remedied by the publication of manuals that instruct users in supervised classification procedures (e.g. Joyce 1977, Whitley 1975).

The purpose of this discussion is to relate the requirements for selecting an appropriate classification system to the distribution of the common shrub communities in the Colorado River Basin.

SHRUBLAND CHARACTERISTICS

Shrublands represent the most widely distributed physiognomic class in the Central Rocky Mountain and Colorado Plateau regions. Shrublands are found at all elevations between 900 m and 3600 m, and are adapted to a broad spectrum of soil moisture regimes ranging from extremely xeric conditions found in the desert near Lake Powell to extremely mesic conditions found in subalpine bogs in the high mountains.

[1]Paper presented at the Integrated Inventories of Renewable Resources Workshop. Tucson, Arizona. January 8-12, 1978.

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Discussion of shrublands here is confined to several distinctive shrubland communities that are found below 2400 m in Colorado and Utah within the Colorado River Basin. Table 1 lists these shrubland communities (phytocoenoses) below according to Kuchler (1965). Table 1 provides a brief description of their distribution, structure and composition, ecological determinants, and CIR signatures.

What are some of the characteristics of shrub communities that affect classification approaches? Some of these characteristics are listed below:

1. Boundaries between communities are sometimes distinct and frequently ill-defined. "Although sharp demarcations between communities can be seen, especially where topographic and/or edaphic changes are sharp, the change in species composition and dominance are rather gentle, particularly where man's disturbances have complicated the use history of the area" (West and Tueller, 1972). Shrub communities frequently form broad ecotones (mixtures) with tree dominated types such as pinyon-juniper and aspen. Sagebrush is an important constituent of many communities even though it is not the dominant species.

2. Species dominance is frequently monotypic in xeric environments. Dominance is shared by more species as the gradient of soil moisture increases. West and Tueller (1972) state that "harsher environments, having fewer species to begin with, have a greater chance of developing monotypically dominated stands and alternes because of less biological mediation of physical environment and accentuated competition where species do meet".

3. Composition and density of shrub species are highly responsive to gradients in soil characteristics, and slope and aspect. The highly variable soils and topography of this region cause important compositional changes over very small distances. As a result many shrub communities are highly heterogeneous in their species composition and density.

4. Density of many shrub communities in desert areas is so low that the underlying soil constitutes the majority of the spectral signature of a particular location.

COMPUTER CLASSIFICATION REQUIREMENTS

Classification of shrublands is an important aspect of recent efforts to perform a supervised LANDSAT vegetation classification as a part of the Regional Land Cover Inventory for the Regional Ecological Test Area Program (USFWS). Test Areas are located in regions experiencing major energy development. The Areas encompassed by this project were northwestern Colorado and southern Utah. The project was funded by the Western Energy and Land Use Team, Office of Biological Services. Coordination of data processing was performed by Dr. Dennison Parker, U.S. Fish and Wildlife Service and by Dr. Eugene Maxwell and Mr. Tom Hart of Colorado State University. The author was responsible for defining a vegetation classification system for each test area, selecting representative training fields for each classification category from large scale (1:31,500) CIR photography, and for verifying the suitability of training sites in the field. These responsibilities permitted an opportunity to incorporate natural vegetation distribution patterns into a classification scheme compatible with digital data processing.

Some of the critical requirements for defining categories and training fields for a supervised classification effort are as follows:

1. Classes must be as spectrally distinct from each other as possible.

2. Training fields should be as homogeneous as possible. "To achieve the most effective results from LANDSAT data it is important that careful consideration be given to the requirements imposed by the assumption of a normal distribution of radiance values. This assumption requires that the radiance detected by the satellite sensors should come from the same mixture of materials on the ground for each pixel within a given class. Hence, the heterogeneities within a class must be small compared to the pixel size. This, and considerations of the reflectance characteristics of materials, should be used as a guide in the selection of classes at the outset of any project." (Maxwell et al., 1977).

3. Mixed classes should be avoided to avoid a bimodal distribution of spectral values within the same class (see 2 above).

4. Training fields should be representative of the same class over a broad area.

Table 1.--Characteristics of common lowland shrub communities in the Southern Rocky Mountains and Colorado Plateau.

Vegetation Type	Dominant Species	Distribution	Height, Cover	CIR Signature
Great Basin - Big sagebrush	big sagebrush (*Artemisia tridentata*) bitterbrush (*Purshia tridentata*) rabbitbrush (*Chrysothamnus* spp.)	widely distributed between 1200 and 2700 meters on dry exposures	Upright evergreen shrubs .5m - 1m tall; cover >50% on bottom-lands; <50% on upland	greenish gray
Saltbush - Greasewood	shadscale (*Atriplex confertifolia*) Nuttall saltbush (*Atriplex nuttallii*) greasewood (*Sarcobatus vermi-culatus*)	widely distributed below 2100 meters in stream and river bottoms in areas with saline-sodic soils	Greasewood; Upright deciduous shrub .5 - 2m tall; cover usually <50%. Saltbush-prostrate deciduous shrub .1 - .5m tall; cover usually less than 20%	greasewood - reddish gray saltbush - gray (usually no discern-ible signature)
Mountain Mahogany - Oak scrub	Gambel oak (*Quercus gambelii*) serviceberry (*Amelanchier* spp.) snowberry (*Symphoricarpos* spp.) chokecherry (*Prunus virginiana*)	widely distributed in foothills area above 1800 and below 2500 meters, mostly on steep slopes and cool slope exposures	Upright deciduous shrubs .5 - 3m tall;cover usually >50%, approaching 100% on mesic sites.	dull red, frequently mixed with sagebrush
Blackbrush	blackbrush (*Coleogyne ramosissima*) Brigham tea (*Ephedra*)	restricted to south-ern Utah near Colo-rado River below 1500 meters mostly on sandy and rocky sites	Upright deciduous shrubs .5m tall;cover usually <20%, dormancy during warm months	usually no discern-ible signature

5. Training fields should be 40 acres in size or greater.

CLASSIFICATION APPROACHES

Considering the characteristics of the shrubland communities (boundaries ill-defined, shared dominance among species, and heterogeneously distributed) in conjunction with the classification criteria outlined above, how is the classification of these shrubland communities to be approached? The following discussion presents the procedures used in the LANDSAT classification in Colorado and Utah.

The initial step was to segregate the vegetation into broad physiognomic groups (forest and woodland, shrubland, herbaceous communities). All ground truth data were then reviewed to determine spectrally separable classes of vegetation without regard to floristics. The data were reviewed again to assign species to particular classes. In the event that several species constituted a class, the imagery was examined to see if species could be further segregated on the basis of their spectral and spatial relationships. For example, it was found that big sagebrush constituted a distinct spectral class. Scrub oak (Quercus gambelii) and Saskatoon serviceberry (Amelanchier alnifolia) could not be successfully distinguished from each other in areas where they were associated.

After establishing base classes, the ground truth data were reviewed to determine the relative extent of ecotones (mixtures) between classes. This exercise was done to determine the necessity of establishing mixed classes, and to determine how two or several classes interacted with each other spatially. Since one of the criteria for selecting training sites is maximum homogeneity, the spatial relationships of the components of an ecotone were examined carefully. If the components consisted of large patches (which was usually the case), then training fields would likely reflect a biomodal spectral distribution of the two components at the level of a single pixel. If the two components were uniformly mixed, then the ecotonal area was defined as a separate class. For example, it was found that sagebrush and serviceberry formed thoroughly intermixed areas on broad uplands in northwestern Colorado. These areas were separated as an independent class. On the other hand, it was found that scrub oak patches occurring in the understory of pinyon-juniper stands were so large that a uniform mixing of the two vegetation types almost never was observed. A mixed class between pinyon-juniper and oak was rejected.

The great heterogeneity of topography and soils in much of the region under study poses a serious problem in establishing training fields that are representative of the same class over a wide geographical area. A possible solution to this problem was formulated by Maxwell and his associates. This approach consisted of stratifying the training fields by soil reflectance characteristics, vegetation density (high and low), by relative illumination (sunny or shaded), and by vegetative vigor (high and low).

After review of characteristic areas for a given vegetation class, a preliminary stratification was established for each class according to the major factors that appeared to control its variability. The ground truth data were then reviewed to determine whether the strata existed commonly for each class. Table 2 illustrates the preliminary and revised stratifications for upland big sagebrush communities. Initially it was believed that there were two important soil backgrounds that would contribute importantly to the signature of sagebrush sites. It was anticipated that there would be two slope aspects at steep slope angles (greater than 15°) that would receive differential levels of illumination. High and low denisty (75%, <50% cover) sagebrush training fields were to be established.

After looking for all eight classes in the preliminary classification, it was found that soil background was sufficiently homogeneous that this factor need not be stratified. It was found that by stratifying the two extremes of illumination that the majority of the sagebrush communities were being eliminated as possible training fields because the majority of these communities occurred on relatively level sites, and were rare on steep slopes. As a result, a level category was added to the aspect stratum. Sagebrush communities occur over a wide elevational range in the region under study. It was found that the understory of sagebrush communities was different in composition and vigor between stands at low elevations and those at high elevations. As a result, an elevation stratum was added to account for these vigor and compositional differences. The high and low density criteria were retained.

The revised stratification results indicated that big sagebrush was not commonly found on steep slopes on either shaded or sunny aspects. Sagebrush was most commonly found on level sites at all elevations. At high elevations it was found at high densities but not at low densities in pure stands because of the presence of tall shrub species such as serviceberry (Amelanchier) and scrub oak (Quercus gambelii). At lower elevations big

Table 2.--Stratification of the upland big sagebrush (*Artemisia tridentata*) class in Northwestern Colorado.

Preliminary Stratification

Soil background (light)				Soil background (dark)			
Slope Aspect (East)		Slope Aspect (West)		Slope Aspect (East)		Slope Aspect (West)	
High Density	Low Density	High Density	Low Density	High Density	Low Density	High Density	Low Density

Revised Stratification

Slope Aspect (East)				Slope Aspect (Level)				Slope Aspect (West)			
Elevation (<2100m)		Elevation (>2100m)		Elevation (<2100m)		Elevation (>2100m)		Elevation (<2100m)		Elevation (>2100m)	
High Density	Low Density	High Density	Low Density	High Density	Low Density	High Density	Low Density	High Density	Low Density	High Density	Low Density
R[1]	X[2]	R	X	N[3]	C[4]	C	X	X	X	R	X

[1]Stratum rarely found

[2]No training fields found in this stratum

[3]Training field used from different class

[4]Stratum commonly found

sagebrush was commonly found at low densities on level sites. A high density training field at low elevations was not defined because a field had already been defined in the bottomland big sagebrush class that adequately represented dense upland stands.

The same procedure was followed to define strata in other classes. A by-product of this sytematic search for different strata in the ground-truth data was a qualitative assessment of the relative abundance of the different strata. These relative abundance data were then applied to a prioritization for analyzing the training field data (training fields for rare strata were eliminated if a reduction in training fields became necessary during data processing).

This systematic approach to classification with an emphasis on "seeing what the satellite sees" permits an initial selection of spectrally distinguishable classes, and emphasizes the collection of training field data covering the variability that may be encountered within a given class. Such an approach is dependent on having comprehensive ground-truth data to cover the full extent of the vegetation variability.

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Panel V — Role of Remote Sensing: Moderator's Comments

Robert C. Heller[1]

Most of you in the audience are aware of what the term "Remote Sensing" means. However, the general public is not so conversant with this terminology. For example, in social situations, I am often asked, "What do you do?"

I respond that I teach Remote Sensing in the College of Forestry. In turn, the questioner's eyebrows are raised until I explain that remote sensing involves using aerial photography, satellite data, and even side looking airborne radar to help inventory natural resources. The response is often, "How exciting!" And it is! Most of us using remote sensing data as a tool to inventory natural resources feel fortunate to be working along the fringes of a newly developing technology. More important, most of us agree that we must use some level of remote sensing data to make integrated inventories in an efficient way.

Tom Hamilton, this morning, brought out the one-world concept--that is, we must work together in making more efficient use of our diminishing natural resources. The photograph of the earth taken by the Apollo 12 astronauts brought most people to the realization that we are indeed fortunate to be living on a planet with such an hospitable environment, and that we must take care of it for our own survival.

Our keynote speaker, Mr. Bettwy, identified one point that is most important to decision makers--the credibility of our output data. It should be accurate and honest. I would like to add some additional issues that need to be identified:

1) Avoid the "gee whiz" syndrome. We are now past the stage where we should report in a subjective manner our obvious natural resource features on remote sensing images.

2) Separate research from pilot testing and operational practice. Too often in papers and reports, these distinctions have not been made clear.

3) Quantify our output data with accuracy statements and appropriate confidence levels. Frequently, this point has been overlooked or avoided in the past. The resource manager needs to have data with known accuracies for his planning and management actions.

4) State the reliability of LANDSAT classifications (of land use, timber types, etc.) in areas outside of training samples. Too often, testing the accuracy of computer-assisted classifications is not undertaken or only with limited sampling. Much effort has gone into development of classification systems, but little expended on adequate sampling techniques.

5) Improve the relevance of LANDSAT classification maps to the user's real needs and objectives. Maps should be geometrically corrected and scaled to match scales of maps most commonly used by the manager.

We have eight speakers on this part of the program who will address several aspects of remote sensing as they relate to integrated inventories of natural resources. The subjects addressed: multistage sampling schemes, computer-assisted classifications of satellite and aircraft multispectral data, and uses of small and large scale color infrared photography. I am sure you will find their papers stimulating.

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Remote Sensing in Multi-Stage, Multi-Resource Inventories[1]

Philip G. Langley[2]

Abstract.--Theoretically, multi-stage, multi-resource inventories which estimate all parameters to the same level of precision by means of common plot structures and intensities are impossible. By means of remote sensing, however, variations in multi-stage sampling designs are possible wherein multi-parameter estimates can be made to a reasonable degree of precision.

INTRODUCTION

If one were to take the title of this paper literally and attack the subject comprehensively, we would be at it for the remainder of this century at least. After all, aerial photography have been used in forest surveys for more than forty years and we are still discovering new applications with new sampling designs to cope with ever more complex resource inventory problems. Added to aerial photography are the more recently introduced methods of remote sensing such as multi-spectral scanners and RADAR[3] which increase our choices tremendously.

From the sampling standpoint, there are compelling arguements against the feasibility of implementing all-encompassing multi-resource inventory designs including only one stage much less multiple stages. For there is no perfect answer to the general question "How does one conduct integrated multi-resource inventories?" Instead, one must balance stated inventory objectives with sampling methods that are appropriate for the cause which in turn must be balanced with the data gathering tools and methods that are available for satisfying the demands of the sampling model(s).

Correllary to the design questions (i.e., sampling frame, method, number of parameters estimated) are the equally compelling questions relating to plot size, configuration, spatial distribution and sampling rules which all must be considered in relation to the characteristics of the populations to be sampled and the distribution of the variables that are measured over space and time. This is the part of inventory design that perhaps falls under the designation of art as much as science but just as important, nonetheless, if an inventory is to be cost effective and meaningful.

In spite of all the apparent incongruities and problems implied in the title of this paper, there are certain frames of reference and principles to guide one to the reasonable solution of complex multi-resource inventory problems with or without multiple stages.

RESOURCE INVENTORY AND REMOTE SENSING

According to the terminology of Forest Sci. Ser. No. 1 (Ford and Robertson, 1971), forest inventory can be thought of in two ways. One is "enumeration," the counting of one or more species generally above a specified size limit, and their classification by size, condition, etc. The second is "forest survey," the determination, on a given area, of such data as soil conditions and topography, together with the extent, condition, composition, and constitution of the forest. When incorporating data from remote sensors in forest inventories, enumeration and sampling are used together in several different ways. Furthermore, the term "multi-resource" carries a much broader connotation than simply 'forest' or 'trees'.

Except in sample plots or in restricted areas, it is seldom possible to obtain detailed information on every unit in a forest because of the high cost and long time involved in gathering the data. Therefore, estimates of population parameters must be derived from sample surveys of one form or another. But visitations to a large number of sample plots on the ground

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[1]Paper presented at the Workshop on Integrated Inventories of Renewable Natural Rewources, Tucson, Arizona, January 8-12, 1978.

[2]Director of Forestry Applications, Forestry Division, Earth Satellite, Corp., Berkeley, Calif.

[3]Acronym for RAdio Detection And Ranging

can become prohibitive when dealing with large wildland areas. For many years now, this problem has been met by employing a form of remote sensing, known as aerial photography, in sampling designs.

Today, of course, we have a large number of implements in our tool box of remote sensing from which to choose (or not choose) as we desire. And the advent of the computer, as well as automatic data recording devices, has greatly broadened the prospects for "enumeration" of population units at some level which in turn expands the list of possible sampling techniques one might employ in a given situation, particularly those which take adventage of supplementary variables and/or stratification (Heller, 1975).

According to the American Society of Photogrammetry (1975), Remote Sensing is defined as "the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon." Clearly, under that definition, aerial photography, as well as other air- and spaceborne sensors such as multi-spectral scanners, infrared sensors, and RADAR, are included. As a matter of fact, under the above definition, several instruments used on the ground, such as relascopes, angle gauges, and dendrometers, are also included although, in this paper, I will restrict my comments to the former group.

THE ROLE OF REMOTE SENSOR DATA

Before discussing the applications of remote sensor data to resource inventories, we should first identify their role in the overall sampling process. Throughout the literature of remote sensing the term "ground truth" is used widely, leading one to believe that data obtained on the ground, such as tree measurements, are used merely to verify or adjust other measurements that are obtained from the remote sensor data. I submit that all estimates of forest parameters are derived from the basic "truths" obtained in the final stage or phase of the sampling design. These data, from the last stage, while sometimes obtained from remote sensors, are usually gathered on the ground.

The main role of air- and spaceborne remote sensor data in resource inventories, therefore, is to provide information that can be employed to increase the precision for a given cost of the estimates derived from ground data. Alternatively, these data are used to decrease the total effort required to achieve predetermined levels of precision. The means for accomplishing these objectives are mainly threefold: (1) to derive better expansion factors which, when applied to sample measurements, result in population estimates having a lower variance, (2) to provide information concerning the forest population that can be effectively employed to reduce the variability at the first stage, as in stratified sampling, and (3) to more accurately distribute estimates of totals to all subareas of the population for use in resource information systems. Resource information systems, in turn, can provide data for increasing the efficiency of new or update inventories over time.

Remote sensor data are particularly applicable to wildland resource surveys in one or more stages because often they can be shown to be cost effective (Langley, 1975, pg. 79). In other words, the value of the information they contribute to a survey more than offsets the cost of acquiring and using them. Furthermore, the cost of acquiring much remote sensor data is charged to other than individual resource survey projects, making them more economically feasible for the ultimate user.

MULTI-STAGE SAMPLING

The concept of multi-stage sampling is, of course, not new. It is discussed in nearly all sampling texts and applications can be found in agriculture, range and forest surveys. Some of the common applications of stratified two-stage sampling in forestry, which employ remote sensing, are management plan inventories incorporating timber stand maps made from air photos. In these inventories, a sample of stands is drawn from each stratum, constituting the first stage. Plots are then laid out within the sample stands constituting the second stage.

The decision to employ more than one sampling stage is largely an economic one. If the required estimates can be obtained at a given level of precision for the lowest overall cost by employing only one stage, the choice is obvious. However, as populations get larger and more variable, making it difficult to address them directly, additional sampling stages become economically more feasible. This is because the additional cost of bookkeeping is more than offset by enabling one to arrive at desired levels of precision with fewer ultimate sampling units. With remote sensing, particularly aerial photography, now solidly established as part of the inventory act, a large amount of a priori information about the quantity and distribution of wildland resources is obtainable. This information is useful not only in designing sampling strategies, it also allows the consideration of a large number of sampling designs which utilize the remote sensor data directly as supplementary variables.

With the advent of high-altitude photography and LANDSAT imagery, there has been an increased interest in employing multi-stage designs in resource inventories covering large areas. Even without employing LANDSAT imagery, various combinations of high- and low-altitude aerial photography have been found to be beneficial. High-altitude aerial photos and LANDSAT imagery cover relatively large areas per frame and are more economical per unit of land area. Their drawback is that, since their resolution is lower, they contain less detailed information concerning the target resource population. Large-scale color photographs, on the other hand, are relatively expensive per unit of land area but contain a wealth of more detailed information. Therefore, when large areas are to be inventoried, some combination of high- and low-altitude imagery sometimes can be used cost effectively in conjunction with ground data from the ultimate sampling units.

In multi-stage sampling, as with many sampling procedures, there is no standard procedure applicable to all resource inventories. The design used in a particular situation should take into account the kinds of population parameters being estimated, the distribution of the population variables used to estimate the parameters, existing information relating to those variables (from remote sensing, say) and finally, the optimum allocation of funds available for the survey.

To increase the efficiency of multi-stage resource surveys using space and/or aerial imagery, it is necessary to somehow translate the remote sensor data to information that relates to the resources of interest. This is where the various techniques of image interpretation or digital image processing come into play. A common example in forestry is the use of timber volume prediction equations based on crown cover and tree height as estimated from aerial photos. After obtaining these data, by sample units, some combination of sampling methods are formulated into an overall multistage design. Stratified, ratio, regression, and probability sampling methods are all possible competitive estimation techniques for use in multi-stage designs.

MULTI-RESOURCE INVENTORIES

From the standpoint of sampling theory, relatively little research has been done concerning 'best' estimators for simultaneous multi-resource inventories employing only one stage. Basically, there is no solution to the problem because of the characteristic differences inherent in the nature and distribution of population variables that are used to estimate each parameter. However, some reasonable approaches to the problem have been tried in an attempt to find solutions that are 'best' in some overall sense--usually lowest total cost for given levels of precision. Some of the early attempts were made by Hazard (1969) and Hazard and Promnitz (1974) who used a mathematical programming approach to optimize multi-parameter estimates on successive occasions. Wensel (1974) discusses the use of weights to optimize multi-parameter estimates in sampling with variable probabilities. Arvanitis (1971) has tried an approach based on the generalized variance and the gradient projection method.

In resource surveys employing only one stage, information from remote sensors can be used to make the design relatively efficient. The problem in multi-resource surveys is that by improving the relative precision in estimating a single parameter, the precision of the others may be lowered (Hazard, 1974). Where remotely sensed digital data are employed, it may be more efficient to reprocess the data base for an entire population, optimizing for single parameters in each case. In multi-stage sampling, on the other hand, there may be greater opportunities for employing common sample units in the early stages when seeking multi-parameter estimates.

According to Murthy (1967, pg. 348), it is sometimes quite feasible to utilize common first stage units and vary the design and sample size in the second stage to arrive at the lowest total cost of an integrated survey. With this approach, overhead costs are kept down at least in the first stage while the relative precision of each estimator is partially controlled in the second stage. This author believes that there are many possibilities for taking this general approach to integrated multi-stage, multi-resource inventories using data from remote sensors. The possible avenues to explore include the following two:

- Stratification before the first or second stage. This can be done manually in the case of aerial or space imagery or digitally in the case of LANDSAT data. The number of sample units drawn from each stratum would vary depending on the parameter being estimated and the distribution of the measurement variables. Conversely, different weights for different estimators may be given to the sample units. The results may be biased but highly precise.

- Common first-stage units may be employed wherein different sampling strategies are used in the second or later stages. This procedure can be used in conjunction with the first method described above.

When utilizing high-altitude aerial or space imagery, multi-stage designs have sometimes employed first-stage sample units of one to four square miles in size (Langley, 1971,1975). When using sample units this large, there are numerous possibilities for at least partially optimizing the design for multiple resource estimation. For example, ownership boundaries which imply differences in management practices as well as resource stratification boundaries can be delineated easily in large sample units. In fact, when the primary unit boundaries are made to conform to the GLO[4] descriptions, much of the variability due to management practices can be either removed or significantly reduced in the author's opinion.

Another advantage of using large primary sampling units, such as square miles (or GLO sections), is the distinct possibility of better estimating population parameters that otherwise are not easily accessible. Surveys for estimating damage from insects and disease fall in this category. Other examples are, (1) estimating the area or volume of timber contained in certain streamside zones which may be subject to restrictive logging regulations, (2) estimating the number of acres in areas subject to high soil erosion hazard, or (3) estimating certain attributes concerning wildlife habitats. All of these kinds of estimates may be facilitated by the use of some form of multi-stage sampling in conjunction with remote sensing and resource information management systems such as TIMBER-PAK (van Roessel, et. al., 1978), of which you will hear more during this meeting. On the operational side, one can take advantage of the economies of clustering in the second stage when employing large first-stage units.

In conclusion, the author believes there are numerous existing possibilities for developing multi-resource sampling strategies in one or more stages by means of remote sensing and data collection in the field. When formulating such inventories, however, one should always consider the relative importance and cost of estimating each parameter and vary the sampling design(s) accordingly. As long as one adheres to the basic principles of good sampling technique, while simultaneously becoming somewhat of a visionary, relatively efficient integrated multi-stage, multi-resource inventories employing remote sensing may even be possible.

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Potential Applications of Satellite Imagery in Some Types of Natural Resource Inventories[1]

Wayne G. Rohde[2]

Landsat satellite imagery has been routinely available to researchers and resource scientists since 1972. Many studies have demonstrated the application of Landsat imagery for conducting inventories and mapping various natural resources. Examples of applications presented in this paper include: timber volume inventory, range productivity inventory, wildland vegetation mapping, inventory of rangeland conversion and irrigated lands, and mapping strip mine disturbance in forested areas. Costs and accuracies for each of these application areas are presented. Landsat data, used in its proper context with appropriate analysis techniques, supporting data, and sound sampling strategies, can be an effective tool in conducting natural resource inventories.

Other Landsat systems, scheduled for launch in 1978 and 1981, will provide continuity in the availability of Landsat data to users. Improvements in the quality and timeliness of data delivered to users, along with improved data handling procedures, analysis techniques, and improved sampling frameworks should increase the use of satellite imagery in natural resource inventories.

INTRODUCTION

Landsat-1 and -2, launched in 1972 and 1975, respectively, have provided resource scientists a tool for acquiring remote sensing data over large regional areas in a cost effective way. These data provide a mechanism for monitoring change in Earth resources, mapping resources over extensive regions, and inventorying specific resources through the use of appropriate sampling procedures. Both satellites record multispectral scanner data for four wavelength bands: green, 0.5 - 0.6 μm; red, 0.6 - 0.7 μm; near I.R., 0.7 - 0.8 μm; and near I.R. 0.8 - 1.1 μm. Landsat-1, designed to operate for one year, was fully operational until the fall, 1977, when MSS band 4 became inoperable. Landsat-1 completely failed on January 6, 1978, and no additional data will be collected with the Landsat-1 system. Landsat-2 is still recording data in all four spectral bands. Future Landsat satellites are planned; thus, satellite data will continue to be available to users. Data from Landsat satellites are available from the Earth Resources Observation System (EROS) Data Center (EDC) at various scales, as black and white or color composite image on film or paper, and computer compatible tapes (CCT's).

Landsat data have been evaluated for mapping and inventory of forest and range resources (Heller and others, 1975; Hoffer, 1975; Bentley and others, 1976; Nichols and others, 1974; Gialdini and others, 1975; Krebs and Hoffer, 1976). Continued availability of Landsat data, improvements in data quality, image analysis techniques, and sampling methodologies will result in increasing use of Landsat data in natural resource inventories.

This paper discusses the application of Landsat and other remote sensing data for several resource inventory and mapping problems. Future plans for follow-on Landsat systems are presented as well as areas where additional research is needed to improve Landsat applications in natural resource inventories.

[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan 8-12, 1978. Prepared under U.S. Geological Survey Contract 14-08-0001-10439.

[2]Technicolor Graphic Services, Inc.

FOREST AND RANGE INVENTORY APPLICATIONS

Numerous studies by several investigators have demonstrated the potential application of Landsat data and multistage sampling techniques with aerial photographs and ground data for inventorying timber volume. Langley (1969) describes the first attempt to use satellite imagery in a multistage sampling framework to estimate timber volume over a 5,000,000 acre (2,023,400 ha) area in Louisiana, Mississippi, and Arkansas. An estimate of 2.225 billion gross cubic feet of timber with an estimated sampling error of 13.0 percent was obtained. It was estimated that stratification of forest from non-forest land on an Apollo 9 photograph and the multistage sampling technique resulted in a 58 percent lower sampling error than would have been achieved without the stratification in an equal probability sampling scheme. In 1973, a study was conducted on the Quincy Ranger District of the Plumas National Forest in California to test the usefulness of Landsat data and multistage sampling to estimate timber volume. An estimate of 11.5 million cubic meters (approximately 2.44 billion board feet) with a sampling error of 8.2 percent was obtained. The estimated cost of the inventory was approximately $.076/ha or $.031/ac (Nichols, Gialdini, and Jaakkola, 1973). Based on the encouraging results achieved on the Quincy Ranger District, the techniques were expanded over the entire Plumas National Forest. An attempt was made to modify the sampling schemes to permit estimates to be made of other resource parameters. Results of the Plumas inventory project are summarized in table 1. The estimated cost of the Plumas Landsat-based timber inventory was approximately $.072/ha or $.029/ac (Gialdini and others, 1975). A similar project was conducted on the Sam Houston National Forest in Texas (Titus, 1976). The project was designed to test, develop, and implement a timber inventory procedure using various data sources including Landsat data, aerial photographs, and ground data. A survey system utilizing U.S. Forest Service vegetation stratification data, large scale aerial photographs, and direct ground measurements was used to estimate the growing stock volume as 384 million cubic feet with a relative sampling error of 7.8 percent. It was concluded that Landsat data were not useful in the Sam Houston National Forest largely because of extreme homogeneity of topographic and vegetative conditions (Titus, 1976). Most recently, major forest inventory projects have been started in the states of Washington, Oregon, and Idaho. The projects are sponsored by the Pacific Northwest Regional Commission in cooperation with the U.S. Geological Survey, the National Aeronautics and Space Administration, and the Washington Department of Natural Resources, Oregon Department of Forestry, and Idaho Department of Lands. Although these projects have not been completed, specific objectives and analysis plans for the Washington and Oregon projects can be found in Aggers and Kelley (1976) and Nichols and others (1976).

Table 1.--Plumas National Forest 1974 Summary of Estimates (from Gialdini and others, 1975).

Parameters of Interest[1]	Estimate Mean/Acre	Standard Error	Relative Standard Error (%)
Number of trees	63.86	7.79	12.19
Square foot basal area	80.69	5.21	6.46
Square foot basal area growth-5 yr	5.41	0.35	6.42
Cubic foot volume	2387.47	186.79	7.89
Scribner board foot volume	16777.05	3173.71	8.19
Square foot surface area	7370.01	465.37	6.31

[1]Conifers, 5.0" DHB and larger.

Various sampling designs involving remote sensing data are commonly applied to resource inventories. Landsat data has provided an additional data resource that when used effectively, can result in more efficient use of aerial photography and ground data. The Landsat data can be used to: 1) define the project area to be inventoried on a uniform data base, 2) divide the project area into sample units, 3) select and locate sample units for sampling. When ancillary data such as ownership, management unit boundaries, watershed boundaries, or land survey boundaries are available in digital format, they can be registered to the Landsat data and further used in stratifying the project area.

With respect to forest inventory, Landsat data are commonly used to stratify forest from non-forest lands. Landsat data have also been used to stratify forested land into broad timber volume classes (Gialdini and others, 1975). In practice, each strata is assigned a weight that is assumed to be proportional to timber volume. A sample unit grid of any user specified size or shape can be placed on the data, and

estimates of volume can be summarized for each sample unit. These estimates are used to allocate second stage samples on which more precise measurements can be made. When the sample allocation is based on variable probability sampling, the Landsat data are also used to calculate the selection probabilities for each sample unit.

Thorough discussions of multistage sampling techniques can be found in Cochran (1963) and Langley (1975).

Although initial forest inventory projects based on Landsat data and multistage sampling have not always met the stated objectives, Landsat data, when analyzed properly and incorporated into a sound sampling framework, offer a potential tool for conducting more efficient inventories. Major areas of needed research include development of techniques and improvement in the quality of Landsat data to improve classification of forest land and subsequent stratification into categories that will improve sampling efficiency. Also needed are more intensive evaluations of alternative sampling strategies.

Results of Landsat-based forest inventory studies suggest the potential use of similar techniques for inventory of range resources.

A study at the University of California, funded jointly by the Bureau of Land Management (BLM) and the U.S. Geological Survey, EROS Program, was conducted to develop multistage sampling procedures for range resource quantification (DeGloria and others, 1975). The general approach was to use Landsat data, medium scale photographs, large scale photographs, and ground data in a multistate sampling framework. (fig. 1). Two planning units within the BLM Susanville District, located in northeastern California and northwestern Nevada, were used to test and demonstrate the approach. The two planning units were Willow Creek, 191,00 ha (472,000 ac) and Cal-Neva, 330,000 ha (816,000 ac). The sample size used in each stage is shown in table 2. The rationale for estimating sample size and the derivation of the sample estimators is described in DeGloria and others (1975). The rangeland productivity estimates for each planning unit are shown in table 3. Although the sampling error ranged from 15 - 20 percent, the investigators felt

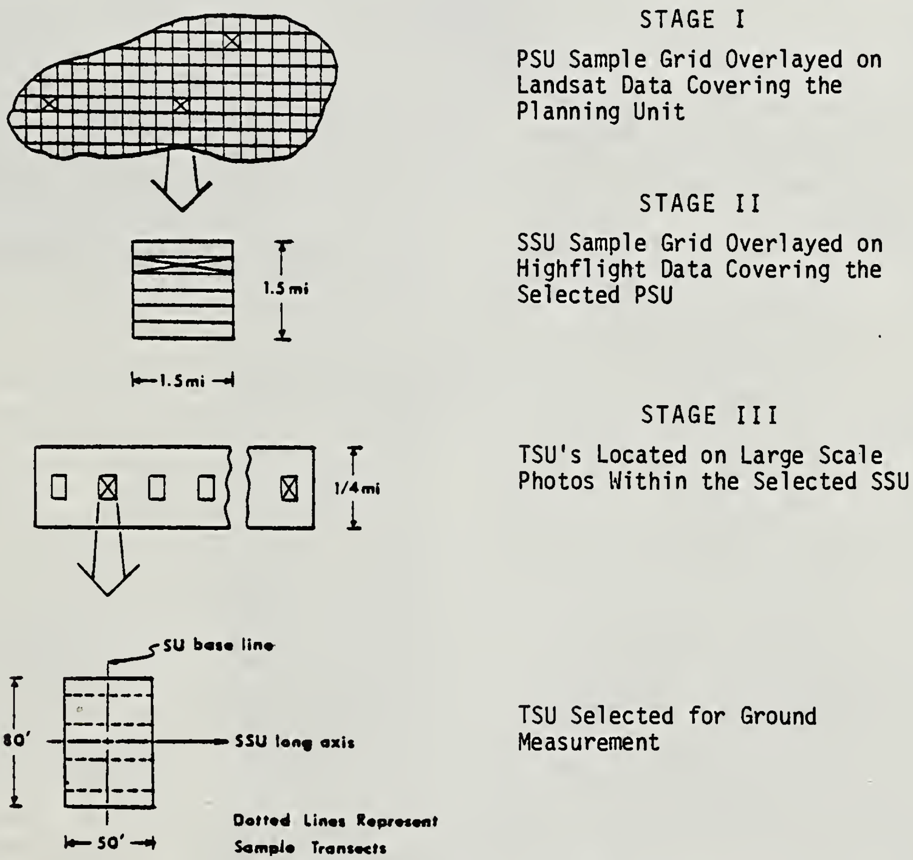

Figure 1.--The Multistage Sampling Frame (From Thomas and others, 1977).

Table 2.--Sample size for range productivity estimation system tested on the Willow Creek and Cal-Neva planning units within the BLM Susanville District in northeastern California and northwestern Nevada (adapted from DeGloria and others, 1975).

Sampling Stage	Willow Creek	Cal-Neva
Stage 1 - Landsat	8 of 400 PSU's[1]	19 of 600 PSU's
Stage 2 - 1:30,000 scaled aerial photographs	8 of 48 SSU's[2]	19 of 114 SSU's
Stage 3 - 1:400 scaled aerial photographs	71 of 71 TSU's[3]	161 of 161 TSU's
Stage 4 - ground	13 of 71 TSU's	30 of 161 TSU's

[1]PSU - primary sample unit
[2]SSU - secondary sample unit
[3]TSU - tertiary sample unit

Table 3.--Rangeland productivity estimates (animal unit month-AUM) using the multistage estimator for BLM land on the Willow Creek and Cal-Neva Planning Units within the BLM Susanville District (adapted from DeGloria and others, 1975).

	Willow Creek (311,000 ac)	Cal-Neva (644,000 ac)
Productivity Estimates	18177 AUM's	33716 AUM's
Standard Error*	3719 AUM's	5175 AUM's
Sampling Error	20.5%	15.4%

*68% level of confidence

that by doubling the number of primary sample units sampled in each planning unit, the sampling error could be reduced to approximately 10 percent (DeGloria and others 1975). Based on the encouraging results of this and other studies within the BLM (Bentley and others, 1976), a major project demonstrating the application of remote sensing for inventory of wildland vegetation has been undertaken. The project is being conducted jointly by the U.S. Department of the Interior (USDI) - Bureau of Land Management, U.S. Geological Survey, EROS Program, and the National Aeronautics and Space Administration. As part of this cooperative project, an effort was undertaken to demonstrate the application of Landsat digital data for classification of wildland vegetation and to assess the accuracy of digital classification results.

Digital image classification techniques were used to classify wildland vegetation and other land cover types on a 118,000 ha (293,000 ac) area near Cantwell, Alaska. Landsat digital data, taken on August 1, 1976, were analyzed using an interactive image analysis system at the EROS Data Center. All picture elements were classified into one of nine land cover types using a maximum likelihood algorithm and training statistics developed with a clustering technique (fig. 2). After classification, a series of control points were selected to develop a transformation so that 1:63,360 scaled map overlays of the classification results could be registered to U.S. Geological Survey 1:63,360 scaled maps (fig. 3). A clustered-stratified random sampling procedure was used to estimate the computer classification accuracy of the nine land cover types. Using sampling for proportion statistics, the overall classification accuracy was estimated to be 84.5% ± 4.2% at the .95 probability level. The cost for mapping wildland resources over 118,000 has was estimated to be $.039/ha ($.016/ac). These results indicate the potential of Landsat data for regional stratification and mapping of wildland resources.

In other resource inventory projects, Landsat data have been used to map and inventory conversion of rangeland to cropland (Draeger, 1978). In a study conducted in western South Dakota, Landsat imagery acquired in 1973 and 1976 was used to estimate the area of rangeland converted to cropland and cropland taken out of production. On each Landsat image, the area of cropland was interpreted and delineated onto 1:250,000 scaled overlays. By superimposing the 1973 and 1976 overlays, maps depicting change from cropland to grassland and grassland to cropland were prepared. A dot grid was used to estimate the area of land within each category. Approximately 15 percent of the area mapped was checked on aerial photographs or in the field, and an error of approximately 2 percent was recorded. The total cost of the inventory of nearly 400,000 ha (988,000 ac) was $200.00 plus five man-days for interpretation (Draeger, written communication 1978).[3]

[3]W. C. Draeger, Principle Applications Scientist, Agriculture, EROS Data Center, Sioux Falls, South Dakota.

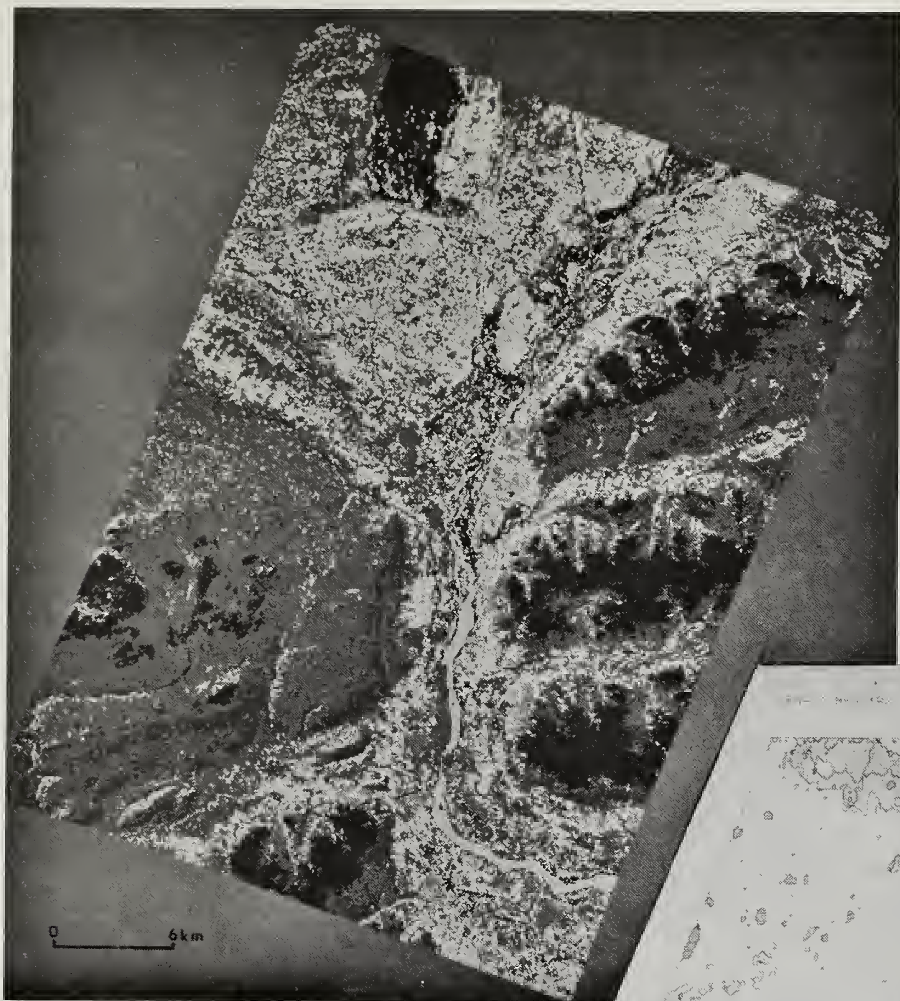

Figure 2.--Landsat classification of land cover types near Cantwell, Alaska. Cover types are in intense colors.

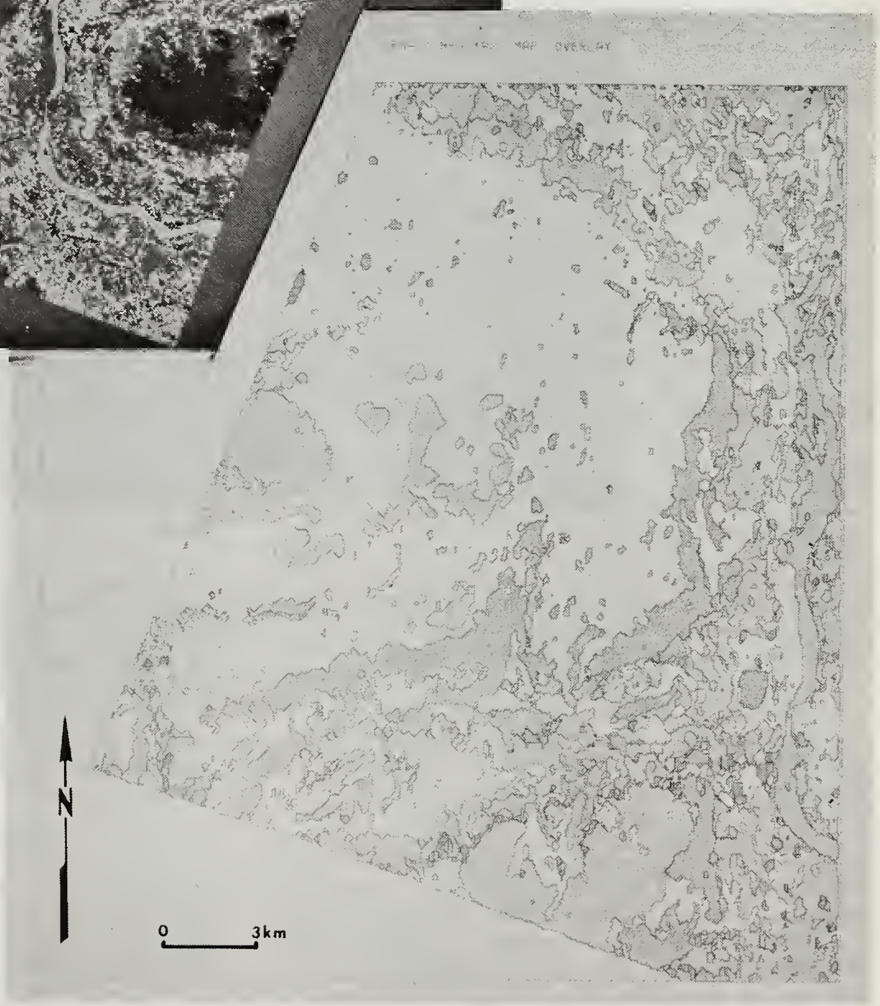

Figure 3.--Example of Landsat classification results that have been geometrically corrected and plotted on map overlay. The map overlay was scaled to register to the U.S. Geological Survey 1:63,360 Healy A2 map sheet. Cover types are in pale hues.

Landsat data have been effectively used to provide estimates of irrigated lands in Idaho (Heller, Ulliman, and Johnson, 1976; Packer, 1976). Multistage variable probability sampling procedures using Landsat imagery and aerial photographs (1:125,000 and 1:8,000) were used to inventory irrigated cropland on three test sites with acceptable levels of accuracy (table 4).

Draeger (1976) describes another technique, based on Landsat data, ground data, and ratio estimators for inventorying and monitoring irrigated land acreage in the Klamath River Basin of Oregon. Irrigated lands were manually delineated, and the irrigated area was estimated with dot grid sampling. Ground data collected on 45 sample plots, each 2.6 km^2 (1 mi^2) in size, were used to calculate ratio estimators to adjust area estimates made in the first phase from Landsat data. Independent estimates, by two interpreters, were 115,000 ha (284,000 ac) and 108,000 ha (267,000 ac). The confidence interval at the .95 probability level was ± 6.8 percent and ±13.0 percent, respectively. The estimated cost of the irrigated lands survey was approximately $1500.00 for Klamath River Basin (approximately 14,800 km^2 or 5,700 mi^2). Clearly, Landsat imagery provides an accurate and effective tool for estimating the area of irrigated lands.

Table 4.--Estimates of irrigated cropland for three sites in Idaho using Landsat data in a multistage sampling framework (adapted from Heller, Ulliman, and Johnson, 1976).

Site	Hectares	Acres	Sample Error@1 Standard Deviation Hectares	Acres	Per-Cent
Western	63,500	156,914	3,589	8,868	6.0
Eastern	224,663	555,162	14,957	36,960	7.4
Silver Creek	7,846	19,388	2,024	5,001	25.8

Landsat data have been effectively used to map and inventory strip mine disturbance in a deciduous forest type near Fort Mountain, Tennessee. Landsat digital data taken in April 1973, were analyzed using image enhancement and image classification procedures. Landsat data of approximately 118,000 ha (292,000 ac) were digitally enlarged, contrast enhanced, geometrically corrected, and recorded onto film with a film recording system at the EROS Data Center. The enhanced image was enlarged to approximately 1:63,560 scale and interpreted to map the area of disturbed lands (fig 4). A standard Landsat color composite was photographically enlarged and interpreted in the same way as the digitally enhanced image.

An interactive image classification system was also used to classify the area of disturbed lands. The data were classified using a maximum likelihood algorithm and training statistics developed with a clustering algorithm.

A stratified random sampling scheme was used to estimate the accuracy of mapping disturbed lands using three different analysis procedures. Based on the area classified as disturbed lands, it was estimated that sixty-one 0.45 ha (1 ac) plots would have to be sampled to estimate an accuracy statement with a confidence interval of ± 10 percent at the .95 probability level. Sixty-one 0.45 ha plots were randomly located on each map overlay. The random points were plotted onto aerial photographs and interpreted as being disturbed or not. Using sampling for proportion statistics, it was estimated that disturbed lands could be mapped from Landsat data with accuracies as follows: 1) Standard Landsat color composite, 65.6 percent ± 12.0 percent; 2) Digitally enhanced Landsat image, 90.2 percent ± 7.5 percent; and 3) Digital image classification, 82.0 percent ±9.7 percent. The cost of interpreting and mapping disturbed lands using Landsat data was estimated as follows: Standard Landsat color composite, $.01/ha ($.003/ac); 2) Digitally enhanced Landsat image, $.05/ha ($.02/ac); and 3) Digital image classification, $.07/ha ($.03/ac).

These results indicate that Landsat digital data can be used to accurately map the extent of disturbed lands, due to strip mining, in a forested environment at a cost of $.05 - $.07/ha ($.02 - $.03/ac). It appears that these data could also provide a cost effective means of monitoring change in areas of disturbed lands.

Results presented here indicate the potential application of Landsat data in natural resource inventories. A major concern to users is whether satellite data will continue to be available and whether there will be improvements in data and data analysis techniques to the extent that users can develop confidence that Landsat data is a viable tool for natural resource inventory.

LANDSAT DATA CONTINUITY

A third Landsat system, Landsat C, is scheduled for launch in 1978, in an orbit similar to that of Landsats 1 and 2. Several changes will be made in the sensors on Landsat C. The multispectral scanner (MSS) will record

Figure 4.--Overlay of disturbed areas delineated on digitally enhanced, enlarged, and geometrically corrected image of an area near Fork Mountain, Tennessee. D represents disturbed lands, C represents conifer-evergreen shrub, H represents deciduous forest, A represents agricultural lands, and M represents mixed deciduous-conifer forest.

data in the same four bands as Landsats 1 and 2 with the same spatial resolution, an instantaneous field of view (IFOV) of 79 m by 79 m. In addition, a thermal channel (band 8) in the 10.2 - 12.6 μm spectral region with approximately 240 m resolution will be added (table 5). The band 8 detector response is specified to give a 1.52°K noise equivalent temperature difference at 300°K. This specification means that an area of the size of six football fields must have a temperature difference of at least 1.0°C over background to be detected by band 8.

Landsat C will also have a Return Beam Vidicon (RBV) television camera system. For Landsat C, a decision was made to increase RBV resolution from 80 m to 40 m and to use one broad wavelength band from 0.505 micrometers to 0.75 micrometers. The resolution of the RBV will be improved by doubling the focal length of the area covered by a single RBV camera used on Landsats 1 and 2.

A fourth Landsat satellite, Landsat D, is scheduled for launch in 1981. This system will have another multispectral scanner, referred to as a Thematic Mapper (TM) with six, or possibly seven, data channels (table 6). The mission parameters for Landsat D have not been completely defined as of January 1978. If the satellite is flown at a recommended altitude of 705 km, the thematic mapper will have a ground IFOV of 30 m for channels 1 to 5, and an IFOV of 120 m for channel 7.

Other recommendations include flying the Landsat D satellite at 918 km and including the MSS used on Landsat C as a prime sensor. The TM could then be used in an experimental mode over selected research areas and minimize data handling problems that may result from the very high data collection rate of the thematic mapper system. The increase in orbital altitude will increase the ground IFOV of the TM from 30 to 40 meters.

Table 5.--Spectral wavelength intervals detected by sensing systems on Landsat C.

Sensing System	Data Band	Wavelength
RBV	1	.505 - .750 μm
MSS	4	0.5 - 0.6 μm
MSS	5	0.6 - 0.7 μm
MSS	6	0.7 - 0.8 μm
MSS	7	0.8 - 1.1 μm
MSS	8	10.2 - 12.6 μm

Table 6.--Possible spectral wavelength intervals detected by Thematic Mapper on Landsat D.

Data Channel	Wavelength	Type of Radiation
1	0.45 - 0.52 μm	visible, blue-green
2	0.52 - 0.60 μm	visible, green
3	0.63 - 0.69 μm	visible, red
4	0.76 - 0.90 μm	invisible, near-solar infrared
5	1.55 - 1.75 μm	invisible, mid-solar infrared
6[1]	close to 2.2 μm	invisible, mid-solar infrared
7	10.4 - 12.5 μm	invisible, thermal infrared

[1]A band close to 2.2 μm is proposed by geologists for research in rock reflectance.

IMPROVEMENT IN DATA QUALITY

Evaluation of Landsat data for many applications has shown that contrast between resource features is often inadequate for accurately and consistently detecting, identifying, and mapping resource features. In many cases, radiometric anomalies resulted in inaccurate image classification, and geometric distortions precluded accurate location of specific features, sample points or plots, and displaying data on a geometrically corrected map base.

While additional studies to evaluate resource applications are being conducted, other studies are underway to develop more efficient image processing and data handling techniques and to develop procedures for improving the data to be made available to users. The EROS Data Center has embarked on a major program to evaluate and implement techniques to improve the quality of Landsat data. Being evaluated are techniques to perform contrast enhancement, edge enhancement, radiometric corrections, and geometric correction (Rohde, Lo, and Pohl, 1978). It is planned that in mid-1978, a digital image processing system will be installed at the EROS Data Center, and users will be able to order film products or CCT (Computer Compatible Tape) products that have been digitally proc-

essing system will result in significant improvements in quality and timeliness of Landsat data products.

While there are still some uncertainties relative to the cost of operating the digital image processing system, the prices of standard digital images products and CCT's are not expected to be appreciably higher than the prices of current Landsat data products. The range and scale of products available (i.e., black-and-white, color, film, paper) will be similar to those provided from Landsat 1 and 2 data.

A new Landsat Data Users Handbook is being prepared by USGS-EDC and NASA-Goddard Space Flight Center. Coincident with publication of the Landsat Data Users Handbook, new order forms and accession aids will be available from the EROS Data Center.

RESEARCH NEEDED TO IMPROVE LANDSAT APPLICATIONS IN RESOURCE INVENTORY

Successful application of Landsat data for natural resource inventories requires additional research in several areas. To efficiently classify Landsat data over large regions, more efficient immage analysis systems and faster image classifiers are needed. Additional studies are needed to develop new classification decision rules that will result in improved classification accuracy and more efficient stratification of Landsat data for allocating samples in natural resource inventories. Techniques will have to be developed to efficiently merge ancillary data, (e.g., topographic data, ownership data, and permanent plot data) with Landsat data. Such ancillary data are useful in improving image classification, stratification, and summarizing resource statistics. Improved data handling techniques will have to be developed to handle increasing amounts of data.

Most applications of Landsat data to natural resource inventories have involved some adaptation of multistage sampling. Just as Landsat is not the remote sensing panacea for resource inventory, neither is multistage sampling, per se, the sampling panacea for resource inventory. Sound, thorough studies of alternative sampling strategies to accomodate the needs of natural resource inventories are needed. Where variable probability sampling procedures are suggested, careful consideration must be given to the assumptions being made with respect to the data extracted from Landsat and the calculation of the selection probabilities. Further consideration of the shape and size of the sample units at each stage or phase is required. Also, an assessment of the optimum scale of aerial photographs to be used at each stage for making measurements with desired precision is needed. Improved techniques are needed to locate Landsat plot data accurately on photographs, maps, or the ground, and to evaluate the error or bias associated with incorrect location of sample plots.

As these problem areas are addressed, the continued availability of improved Landsat data, image analysis techniques, and sampling methodologies should result in increasing use of Landsat data in natural resource inventories.

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Satellites for Practical Natural Resource Mapping? A Forestry Test Case[1]

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Arthur G. Dodge, Jr.[3]
Samuel D. Warren[4]

Abstract.--In this cooperative project we compare computer classified Landsat maps with a recent inventory of forest lands in northern Maine. Over the 485,000 acre area, acreages of softwood, mixed wood, and hardwood agree to within 5 percent. These results show enough potential to warrant our further development of computer-satellite mapping techniques for use in practical forest inventories.

In this project we think we have come one step closer to answering the question: Does satellite remote sensing have a place in practical natural resource inventories, and if so, where? The ultimate answer comes from the user, not the researcher. To give a realistic answer the user must see how the techniques perform when there is a real need for information. In this project, through cooperation with the user, we were able to choose a forest management district which was being inventoried, as an area on which to test computer-satellite mapping techniques. The need for information was there, and the user was there to evaluate the test.

BACKGROUND

Information from Landsat satellites, launched by NASA in 1972 and 1975, has been used to map natural resources and cultural features (Bishop 1976, Enslin et al 1977, LARS 1977, Petersen and May 1976). Researchers in various parts of North America have reported use of Landsat data in mapping forest resources (Kourtz 1977, Mead and Meyer 1977, Sayn-Wittgenstein 1977, Williams and Haver, 1976).

In New England, representatives of the Goddard Institute for Space Studies, Dartmouth College, and the University of New Hampshire Cooperative Extension Service have combined efforts to produce general forest type maps of some areas in New Hampshire from Landsat data (Dodge and Bryant 1976). Under NASA Grant NSG 5014 we were authorized to continue developing methods for applying Landsat data to actual field forestry situations.

In 1975, Dodge and Bryant showed some examples of the computer-satellite maps to personnel at the Seven Islands Land Company. This company manages 1.7 million acres (690,000 hectares) of forest land in northern Maine and New Hampshire. Company representatives felt that these early examples were good enough to warrant investigation into the possibility of mapping forest land with a satellite. The idea was to get low cost, large scale maps for tax reporting, road location, and cut location. The first concern was to make the printout maps geometrically correct, and the next was to have a means of tallying acreage with arbitrarily defined boundaries. Both of these problems were solved by the next year. Even though Seven Islands had no pressing need to map with a satellite, they felt that future developments of technology and politics might make this type of remote sensing financially attractive if not completely necessary.

PROJECT INITIATED

In 1976, Seven Islands was planning an

[1]Paper presented at National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan 8-12, 1978.

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intensive inventory of the lands they manage. This provided an opportunity to compare Landsat mapping, still in the development stage, with an up-to-date operational inventory. We could compare both content and cost of the information. The intention here is not to replace current techniques with satellite mapping, but to see if the satellite data can fit into the inventory scheme. The initiation of this project brought together three separate points of view. These came from the person representing the potential users (Sam Warren), one who could produce computer-satellite maps (Emily Bryant), and one who knew how to listen to the first two and help them combine their efforts (Gibb Dodge). Each played a key role in the project.

We agreed upon the following goals:

1) Map and measure general forest types, non-forest types, water, and roads in three townships that Seven Islands manages, using computer classification of Landsat data. The categories were chosen to correspond with categories in the Seven Islands inventory. (This goal eventually was expanded to include mapping the entire Ashland District.)

2) Calculate area for each category by township.

3) Produce a 1:24,000 scale geometrically corrected computer printout map for the area.

4) Do all this with minimal initial ground truth.

5) Keep track of expenses--human and computer time as well as cost of data and supplies--to give an idea of cost per acre.

DESCRIPTION OF ASHLAND DISTRICT AND SEVEN ISLANDS INVENTORY

The Ashland District, managed by Seven Islands Land Company, consists of land in 29 townships in northern Maine between 46 and 47 degrees north latitude. In most of the area, the political subdivisions are "unincorporated townships" where there is very little permanent human settlement. Forest products and recreation have been the main activities over the past two centuries. The individual parcels or townships in the Ashland District are not always contiguous, and range in size from 1,000 to 26,000 acres (400 to 10,500 hectares). The District comprises a total of 485,310 acres (196,398 hectares) (fig. 1).

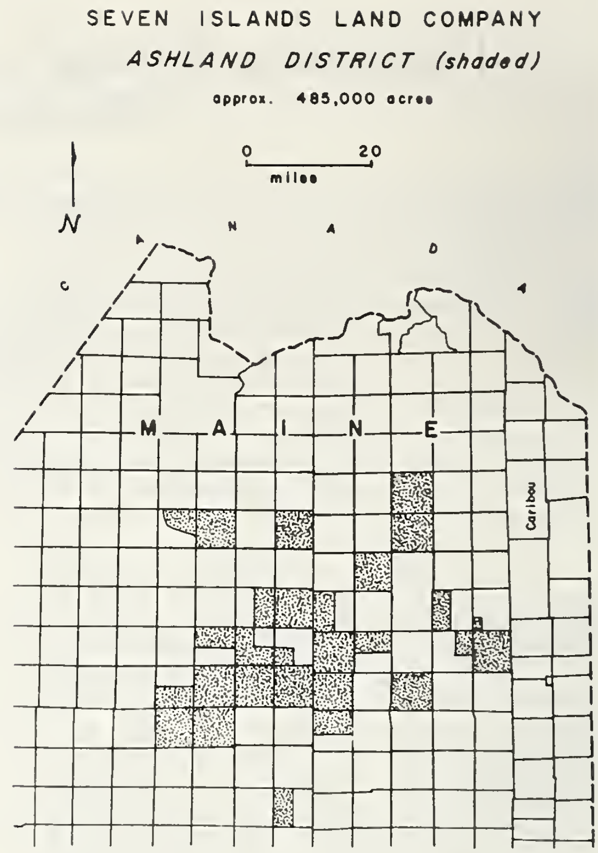


Figure 1.--Location of forest land management district which was mapped using computer-satellite techniques.

The most common forest types in this area are:

spruce - fir (*Picea sp.* - *Abies balsamea*)
maple - beech - birch (*Acer saccarum* - *Fagus grandifolia* - *Betula alleghaniensis*)
northern white cedar - black spruce (*Thuja occidentalis* - *Picea mariana*)
aspen - birch (*Populus tremuloides* - *Populus grandidentata* - *Betula papyrifera*)

The types are not distinctly separated as in some other regions such as southeastern and western United States (fig. 2).

As a result of the Seven Islands land management philosophy, most of the harvesting operations are partial cuts.

Figure 2.--Oblique view of forest land in Ashland District. The forest types are not distinctly separated as in some other regions of the country.

The inventory which Seven Islands started in 1976 is based on improved techniques of aerial photo interpretation, "3-P" field sampling, and the "STX" computer program. There are two kinds of information in the inventory: maps and volume estimates. The maps distinguish vegetation by type, size, and density to a 10 acre minimum. Forest types are broken down further by species where possible. The forest types are grouped as follows:

softwood - 75-100% conifer
hardwood - 75-100% deciduous
mixed wood - remaining forest vegetation

The map information is stored by forest stand on computer tape. Volume estimates are given for the whole district by softwood, mixed wood, and hardwood with accuracy specified as ± 10% for softwood and ± 15% for hardwood at odds of 9:1. The figures are broken down by townships as well, but with no accuracy limits specified.

PROCEDURE

Computer processing was done using the computer facilities and software of the Goddard Institute for Space Studies (GISS), in New York City, through a remote terminal located at Dartmouth College in Hanover, New Hampshire. The satellite inventory of the Ashland District employed computer classification of Landsat computer compatible tapes. The satellite data were collected on 6 July 1976 (scene identification number 5444-14073) and 11 August 1976 (scene identification numbers 5480-14040 and 5480-14043). We used the GISS algorithm in our supervised classification.

Landsat satellite data consists of measurements of average reflectance from each acre on the ground in each of four spectral bands: green, red and two near infrared. Our procedure in making computer classified maps from this data is usually as follows. For each desired cover type category in the classification, e.g. softwood, hardwood, water, or open land, we select one or more well defined, representative areas on the ground--these are called training sites. We assume that the reflection measured for a training site is typical of its cover type. Computer program parameters are set so that in a classification all areas with reflection similar to that of a training site are assigned to that training site category. Once parameters are set for all categories, we compare the resulting computer classification with ground truth for all the training sites, and adjust the parameters to give the optimum classification. This is then extended to map the whole applications area.

The first step in this project was to define the categories to be used in the satellite classification. The fine cover type distinctions such as species and size of trees, which were called for in the Seven Islands inventory, and are possible using aerial photos, are not possible using Landsat data. We therefore grouped the many Seven Islands categories into three categories: softwood, mixed wood, and hardwood, distinctions we have been able to make with Landsat data previously.

Our ground truth consisted of representative black and white aerial photos produced from color infrared transparencies (1:15,840), an overflight of the area, prints of photomosaics used for cut locations (1:31,680), and topographics maps (1:62,500). We had no actual sample of the Seven Islands categories. There were two reasons for this: first, the information was not yet available, and second, we wanted to minimize amount of ground truth used.

We used a variation on our usual classification procedures, a method we call "rational signatures," to define the mixed wood category using only pure softwood and pure hardwood training sites. We classified the three townships agreed upon originally. By the time we completed this, the Seven Islands inventory was available and we could compare results. We found that although the total forest acreage was close (within 3%), and the general location of types seemed good, the acreage of softwood, mixed wood, and hardwood categories varied too much from the Seven Islands inventory to be of practical use. Softwood was 22% low, mixed wood 71% high, and hardwood 38% low. Apparently our interpretation of the

categories differed from the photo-interpreter's, even though they were based on the same definitions.

We decided to lower our sights for the fourth goal (minimal ground truth), and included in our ground truth the Seven Islands results for one township. We adjusted parameters until the computer acreage figures for softwood, mixed wood and hardwood agreed with the Seven Islands figures for that township. Thus the whole township became a training site. Results on the other two townships improved, but there still were discrepancies. This brought us all to the conclusion that we should classify the whole district in hopes that the differences would balance out over a larger area. We made a final refinement of the classification and mapped the whole district.

A significant part of the effort in this project went into locating the boundaries of all 29 townships (fig. 1), and feeding them into a masking program which allows acreage tallying within specified boundaries. We used topographic maps to define the township boundaries. Water bodies were the major control, although vegetation patterns helped since they follow the topograhy.

RESULTS

A printout map and tally was made for each township in the district. The tally for the whole district is given in Table 1.

Differences in forest type measurements between the computer and Seven Islands are under 5% for the whole district but are larger for the individual township tallies. The average size of a township or part of a township is 16,732 acres. The average differences for the average township are:

± 10.3% -- Softwood
± 13.0% -- Mixed wood
± 16.0% -- Hardwood
± 1.8% -- Total Forest

See Appendix A for further detail on acreage mapped vs. difference.

Figure 3 is a sample comparison of the 1:24,000 scale geometrically corrected computer printout map with the Seven Islands inventory map and aerial photos from which the Seven Islands inventory was done. This covers part of one of the townships used as training site. At first glance the general forest types appear to be located accurately. A quantitative measure shows overall agreement of about 60%. Details are in Appendix B.

A very rough estimate of cost is 1.4 cents per acre. This includes cost of ground truth, satellite data, computer time, and human time figured at $10 per hour, and excludes cost of developing software and the initial cost of the computer.

Table 1.--Comparisons of Seven Islands Land Co. and computer measurements of forest types - Ashland, Maine District

Category	Seven Islands Acres	Seven Islands %	Computer Acres	Computer %	Difference Acres	Difference %
Softwood	215,285	44.4	219,683	45.3	+4,398	+2.0
Mixed Wood	177,895	36.7	184,127	37.9	+6,232	+3.5
Hardwood	67,924	14.0	64,561	13.3	-3,363	-5.0
Water	14,609	3.0	11,605	2.4	-3,004	-20.6
Open Land	2,035	0.4	1,639	0.3	-396	-19.5
Bog	7,562	1.6	599	0.1	-6,963	-92.1
Unclassified	-	-	3,102	0.6	+3,102	-
Total Forest	461,104	95.0	468,371	96.5	+7,267	+1.6
Total Area[1]	485,310					

[1]In both the Seven Islands inventory and the computer-satellite inventory, the acreage tallies for each township have been multiplied by a factor to match the total deeded acres for the township. This is because for any given township, there can be up to four figures for total acreage (from different sources); these can vary by as much as 10%.

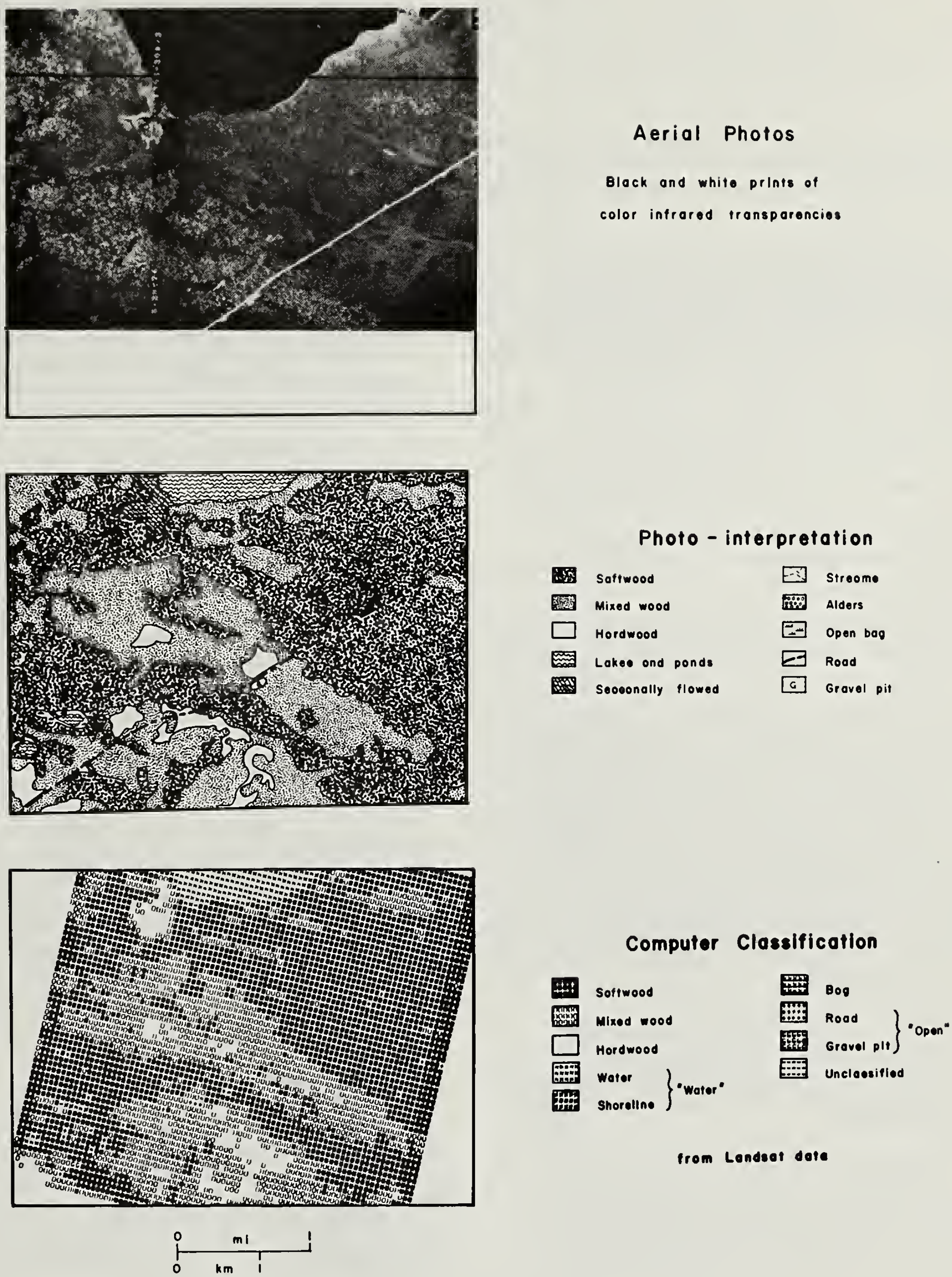


Figure 3.--Comparison of same area on aerial photos from which inventory was made, Seven Islands type map and geometrically corrected computer printout map (scales modified to be equal).

DISCUSSION

We would like to make the following observations about the results:

Bogs were often classified as mixed wood or hardwood, except where there were no trees at all, leaving the large discrepancy (-92.1%) in the bog category.

The difference in the water and open categories (roads and gravel pits would be included in the open category) is because the features are small relative to the resolution of the satellite. Narrow roads and streams, easily recorded by the photo-interpreter, are swallowed up in the surrounding types in the satellite data. Major truck roads were not located with enough accuracy to be useful. They could be recognized only if we already knew that roads existed in the area.

The unclassified areas generally occurred along shorelines of lakes and ponds or in open areas.

There was some misclassification of pure hardwood areas (mostly on the sunny side of a ridge) as bog.

When we examined one of the townships which had large differences in general forest types, we found that a sizeable portion of it had been partially cut in the last several years. When we looked at the aerial photos of the areas, we saw that there is a large percentage of softwood stems remaining after harvest, but the residual large hardwood crowns make the average reflection similar to mixed wood. Some of these areas are classified as softwood by the photo-interpreter and mixed wood by the computer.

Shadowing also affects the computer classification, giving an overestimate of softwood in shadowed areas and an underestimate in sunny areas. This seems to balance out over larger areas.

A large part of the 1.4 cent per acre cost is human time. With practice and with specially-tailored software, human time involved could be minimized, probably reducing the cost to less than 1 cent per acre.

EVALUATION

This evaluation is largely the opinion of our representative of the user; the other authors concur.

We felt that the results of mapping the 485,000 acre Ashland District were good for the totals of softwood, mixed wood, and hardwood, these being very close to figures we arrived at with our conventional forest inventory.

One of our reasons for making an inventory is tax mapping. Maine has a tree growth law which taxes each broad forest type (softwood, mixed wood, or hardwood) at a different rate. The townships, and sometimes parts of a township, have complex ownership patterns. Each individual owner receives a tax bill. It is important, therefore, to classify accurately relatively small parcels of land, sometimes less than 1,000 acres. Since we found that some townships showed large differences from the Seven Islands inventory, we could not use the satellite maps as they are now for tax purposes.

The problems with the current satellite maps seem to us to be centered around the satellite's resolution. There are two ways we can see to approach them. One, we can hope that future generations of satellites will have better resolution. Perhaps then we could distinguish a partial cut in a softwood stand from an uncut mixed wood stand, as well as identify new road systems, streams, insect damage, and textures in the forest canopy which might correlate with age or species. Landsat D will have quarter acre (0.1 hectare or 30 meter) resolution; this may or may not meet our needs. We need the same accuracy for the 1,000 acre parcels as we had for the 485,000 acres using one acre resolution. Gauging by the graphs in Appendix A (acreage vs. difference), the percent difference with one acre resolution increases substantially for parcels under 100,000 acres. One logical but perhaps impractical extrapolation of this is that we need a minimum of 100,000 resolution elements in a parcel to maintain acceptable accuracy. In which case, resolution of 1/100 acre (about .004 hectare, or 6.4 meters) should give us respectable accuracy on 1,000 acre parcels.

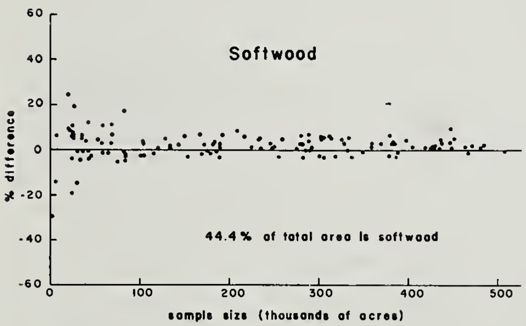
The second approach is to measure changes from year to year. This may give us added information even without higher resolution. For instance, it does appear that our cutting practices change overall crown reflectance from softwood to mixed wood and this may show up on classifications using satellite data of an area before and after a cut. (Williams and Haver, page 15).

We have to test the consistency of computer-satellite mapping year to year, over known areas including those that have not changed, as well as those that have. Consistency is essential if the satellite mapping is to be used to update inventories.

As of now, I think our time is well spent on this kind of investigation. In view of the energy problems we are having and will continue to have, the use of satellite data in forest inventories will become more important as a supplement to aerial photographs. This may well become a new technique to be included in our future inventory.

APPENDIX A
ACREAGE VS. DIFFERENCE

The graphs in figure 4 indicate how percent difference between Seven Islands and computer-satellite acreage figures varies with the size of the area mapped. Groups of townships were chosen at random (with replacement) from the 29 townships in the Ashland District, and acreage difference in softwood, mixed wood, and hardwood categories were calculated for each group.



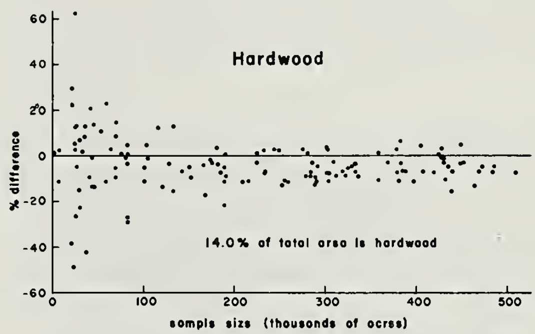


Figure 4.--Percent difference vs. size of area mapped in each of the three major forest types.

APPENDIX B
LOCATIONAL AGREEMENT

Table 2 shows locational agreement between the computer classification and the 1:15,840 scale forest type maps made from aerial photos for the Seven Islands Land Company. We chose 200 one-acre (one pixel) samples at random from one of the townships which was used as a training site. The location of the samples was projected onto the type map from the 1:24,000 scale computer printout map. The projection process introduces about a 250 foot (75 meter) uncertainty in the location of the samples on the type map.

Of the 200 samples, 130 fell within the township boundaries. Water was used as control, so the entries for water are not as meaningful as those for the other categories. We would like to point out that the locational agreement is dependent upon the accuracy of human interpretation, ground truth at two or more scales, and equipment used to modify scales, as well as the accuracy of the computer classification.

Table 2.--Comparison of Seven Islands and computer location of forest types in one township of the Ashland, Maine District

		Photo-interpretation							
		Soft-wood	Mixed Wood	Hard-wood	Water	Open	Other	Total	Percent Agreement
Computer Classification	Softwood	41	12	1	1		3	58	71
	Mixed Wood	16	23	3			2	44	52
	Hardwood		8	6			1	15	40
	Water				12			12	100
	Open								
	Other			1				1	
								130	63 overall 59 forest categories

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Mapping Vegetative Cover by Computer-Aided Analysis of Satellite Data[1]

Roger M. Hoffer and Michael D. Fleming[2]

Several techniques involved in digital analysis of data from satellite scanner systems are discussed. Major cover types for a mountainous test site of approximately one million hectares were mapped with an accuracy of over 85% using both Landsat and Skylab data. Acreage estimates based on computer analysis of satellite data were compared to photo interpretation estimates, resulting in correlation coefficients ranging from 0.93 to 0.97. Topographic data (elevation, slope, and aspect) were digitally overlayed onto the satellite data, creating a data base that enabled various map products to be produced for resource management purposes.

INTRODUCTION

In many disciplines, the need for reliable and timely resource information is critical. Because of the extensive and dynamic nature of the world's agricultural and forest resources, the synoptic type of data that can be obtained at regular intervals from spacecraft altitudes has many potentials. The launch of Landsat-1 (previously ERTS-1) in 1972 has clearly shown the capability to obtain high quality data in a quantitative format. As the potential value for this type of data becomes more apparent, many questions are raised concerning techniques that can most effectively handle and analyze such large quantities of data. One approach, which was first attempted in 1966 at the Laboratory for Applications of Remote Sensing (LARS), Purdue University, utilizes pattern recognition theory applied to measurements obtained from multispectral scanner (MSS) systems. This approach was initially developed for agricultural situations and involved data obtained from aircraft altitudes. In the last few years, modification and refinement of the basis procedures, followed by extensive testing with Landsat and Skylab data has proven that computer-aided analysis techniques can successfully map and tabulate various earth resources using data obtained from spacecraft altitudes.

It is the purpose of this paper to briefly discuss the basic steps involved in computer-aided analysis of multispectral scanner data, and then to describe the results of some of our work using these techniques applied to both Landsat and Skylab data for purposes of mapping forest and other major cover types.

TECHNIQUES FOR COMPUTER-AIDED ANALYSIS OF SATELLITE MSS DATA

The digital processing and analysis of data from Landsat or other multispectral scanner systems normally involves several major steps, including:

- Data Reformatting and Preprocessing
- Development of Training Statistics
- Classification of the MSS Data
- Evaluation of the Classification Results
- Display and Tabulation of Information (for Resource Management or Other Purposes)

The data reformatting and preprocessing can include several types of activities, such as reformatting Landsat data to allow a full frame to be contained on a single 9-track, 1600 b.p.i. data tape; geometric correction

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and scaling the data to a specified map base; overlaying multiple sets of digital data; etc. Due to distortions in "bulk" or "system corrected" Landsat data tapes, the geometric correction process developed by Anuta (1973) to rotate, deskew, and rescale Landsat data without causing any changes in the radiometric values of the data has been of great value. The usual output of this process is a geometrically corrected data tape which, if every resolution element or "pixel" is displayed on a standard computer line printer, results in a 1:24,000 scale alphanumeric printout, oriented with north at the top. This scale allows the analyst to superimpose the Landsat data directly on 7½ minute U.S.G.S. topographic map (or other 1:24,000 scale maps or images). Such a capability has proven very beneficial to the analyst for accurately locating various features in the satellite data printouts.

The concept behind most computer-aided analysis techniques involves a man/machine interaction, whereby the man "trains" the computer to recognize specific combinations of numbers that represent reflectance measurements in each of several wavelength bands, for the cover types of interest. This training process involves fairly limited areas for which accurate information exists concerning the type and condition of the ground cover. After a representative set of training statistics have been developed, the computer is programmed to classify the reflectance values for each resolution element (or a statistical subsample thereof) in the entire data set. In this way, the speed of the computer is used to advantage and a large geographic area can be mapped and acreage tabulations obtained at a much faster rate than would be possible using normal image interpretation techniques.

The development of training statistics and the actual classification of the data are often considered to be a single task. Much attention has been given to the various algorithms that can be utilized to classify the data, but relatively little emphasis has been given to the procedures used to train the classifier. However, it is our belief that the process involved in developing the training statistics is very critical, and indeed is the key to effective use of the computer for mapping vegetative cover using satellite MSS data.

The most common approach used for developing training statistics is the so-called "supervised training fields" technique, whereby the analyst designates to the computer the X-Y coordinates of "training fields" of the various cover types which have informational value or are of interest. For example, at a certain X-Y location in the data is a stand of ponderosa pine; a stand of aspen is at another location; other areas contain Douglas fir, grassland, water, etc. This supervised technique has been used quite effectively for agricultural mapping (Bauer, 1973), and several forestry application studies have utilized this technique, but the varying degrees of success (Bryant and Dodge, 1976; Williams and Haver, 1976; Mead and Meyer, 1977). Our own experience, involving analysis of Landsat data in nine different states and a wide variety of conditions and cover types, has shown that for wildland areas, where the cover types of interest are often not spectrally homogeneous, use of this supervised technique often does not yield acceptable accuracy or reliability. The primary reason for this is the difficulty for the analyst to define locations in the data that represent <u>all</u> significant variations in spectral response for every cover type of interest.

Another approach to developing training statistics is the so-called "clustering" technique (sometimes referred to as the "nonsupervised" technique). With this approach, the analyst simply designates the area to be classified and the number of spectrally distinct classes into which the data should be divided. The computer is programmed to classify the data into the designated number of spectral classes and prints out a map indicating which resolution elements in the data belong to which spectral classes. The analyst then relates this classification output map to aerial photos or surface observation data, and determines which resources are represented by each of the spectral classes (e.g. Spectral Class 1 is aspen, Class 2 is ponderosa pine, etc.) Experience has shown that this technique effectively overcomes the primary limitation of the "supervised" approach, but when working with large areas, the amount of computer time involved in the interative clustering sequence makes this technique very expensive. In addition, the number of spectral classes defined is often very large, since a single cover type of interest is usually represented by several spectral classes. In areas where the vegetative cover is complex (e.g. small stands, variations in stand density, species mixtures, etc.) it is often difficult to reliably relate each of the spectral classes defined by the computer to the vegetative cover type.

A recently completed research project has shown that several methods can be utilized to combine various aspects of the "supervised" and the "clustering" techniques, and that the resulting hybrid techniques can cause significant differences in the amount of analyst

time required, computer time required, and classification accuracy achieved (Fleming and Hoffer, 1977). The most effective procedure defined to date is described as the "Multi-Cluster Blocks" technique for developing training statistics. In this method, several small blocks of data are located, each of which contains several cover types and spectral classes (Figure 1). Each data block is individually

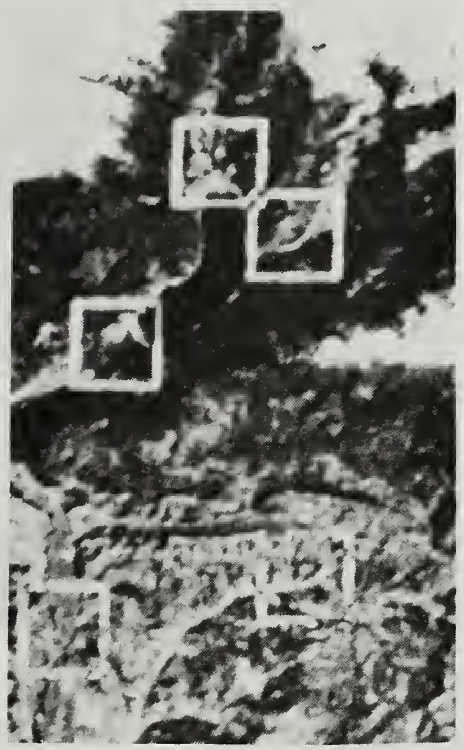

Figure 1 — Digital Display Example of Landsat MSS Data with Several Training Cluster Blocks Defined.

clustered and then the spectral classes for all cluster areas are combined to form a single data deck which statistically describes the spectral characteristics of all cover types in the entire study site. In most situations, each cover type of interest is represented by several spectral classes in the MSS data. In essence, this Multi-Cluster Blocks technique entails discovering the natural spectral groupings present in the scanner data, and then correlating the resultant spectral classes with the desired informational classes (cover types, vegetative conditions, etc.). In most cases, less than one percent of the data involved in the final classification is utilized in this training phase. However, it has been shown that the classification results can have significantly higher accuracy (e.g. 14%) when the Multi-Cluster Blocks technique is utilized rather than the more common Supervised technique (Fleming and Hoffer, 1977). Most studies to date which have been directed at mapping forest cover by computer-aided analysis techniques using Landsat data have utilized the Supervised technique, but often the results have been less than satisfactory (e.g. Mead and Meyer, 1977). Therefore, we believe that the development of a more effective technique to develop training statistics offers a significant improvement in the potential utility of these computer-aided analysis techniques and satellite data sources.

After the training statistics have been defined the next step in the analysis process involves the actual classification of the data. In the classification, the measurement values of each resolution element "sensed" by the scanner system are assigned to one of the spectral classes defined by the training statistics. One of several different algorithms can be utilized to classify the data. The "Maximum Likelihood" algorithm based upon an assumption of a Gaussian distribution of the data is one of the most powerful and widely utilized algorithms, and is the one used to obtain most of the results reported later in this paper. Other algorithms such as the Minimum Distance of the Means, Table Look-up, Parallelepiped, etc. can also be used, but these have generally been found to be less accurate than the Maximum Likelihood algorithm, although they are faster.

Most classifications of satellite MSS data involve an independent classification decision for each resolution element in the data. This results in a very detailed classification map. Indeed, the amount of detail is sometimes more than is needed or desired by the user agency, since the classification maps may have a "salt and pepper" appearance in areas where there are many small (i.e. 1-3 acres) areas of different cover types. A new classification technique called ECHO Extraction and Classification of Homogeneous Objects) enables the computer to define areas of the same general cover type and then classifies the entire area in a single classification decision. With this technique, individual resolution elements that are spectrally different from the surrounding data are grouped into the surrounding cover type. Therefore, the resultant classification map looks much like a normal forest cover type map obtained by standard techniques. Depending on the particular application, some users express preference for the detailed per-point classification cover type maps, while other users prefer the more generalized ECHO map products. Figure 2

shows an example of each, and indicates the

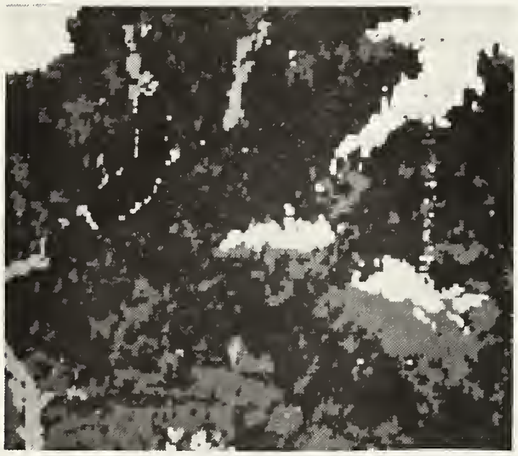

Figure 2 -- Comparison of Detailed Per-Point Classification Map (TOP) and more Generalized "ECHO" Classification (Bottom) Using Skylab MSS Data. White=Snow; Off-White=Exposed Rock & Soil; Light Grey=Pasture; Medium Grey=Deciduoud Forest; Dark Grey=Coniferous Forest; Black=Water.

potential for using different techniques to produce various levels of detail in the map products.

After the data is classified, the results should be evaluated to determine if they are reasonably accurate. It is not difficult to classify or map a large geographic area very rapidly using computer analysis techniques, but unless the resultant classification is accurate and/or reliable enough to meet the users' requirements, the results are of little practical value. Several techniques have been used to evaluate the classification results, including both qualitative and quantitative approaches. The most common qualitative approach is to visually compare a classification map to an aerial photo or cover type map of the same area. A more quantitative approach involves designating a large number of "test areas" on which the actual cover type is known (Figure 3).

Figure 3 -- Landsat-1 MSS Band 5 (0.60-0.70μm) image of the Vallecito Reservoir study area showing the location of the test fields used to evaluate the classification accuracy.

The actual computer classification is then compared to the "correct" classification and a result is expressed in terms of classification performance or percent of the data points that were correctly classified. Tables showing both inclusive and exclusive errors can also be easily produced and studied to determine causes of classification errors (see Table 1). If acreage estimates for the various cover types are available or if they can be obtained from aerial photos, one can also compare these to acreage estimates from the computer classification results for the same areas (e.g. townships, sections, quadrangles, watersheds, etc.).

If the evaluation of the classification results indicates that they are reasonably accurate, the final step in the use of computer-aided analysis techniques is to display and tabulate the data in a format specified by the

user. Different users require different scales of map outputs or may have specific requirements for tabular results. If the results of analysis of remote sensor data are to be truly useful, the results must be provided in a format that is suitable to meet the particular needs of the various user agencies and individuals. Figure 2 showed examples of maps that can be obtained in black and white or in color from various types of output devices. Another common output format (particularly in research programs) is the computer line-printer map, in which different alphanumeric symbols are used to represent the various cover types. An example of this type of computer-generated map is shown in Figure 4a. Figure 4b shows the same classification results, but in this case, the final output map was generated on a Calcomp plotter, thereby producing a map format that is preferred by some users.

RESULTS OF MAPPING FOREST COVER BY COMPUTER-AIDED ANALYSIS OF SATELLITE DATA

Several studies involving use of computer-aided analysis techniques on Landsat and Skylab data have been conducted for different areas in the Rocky Mountains of Colorado. These studies have involved the classification and mapping of forest cover and other major cover types to determine the capabilities and limitations of computer-aided analysis techniques in areas of significant topographic relief. Many researchers have carried out studies involving flat-land areas where the topographic effects on spectral response are negligible. However, because a significant proportion of the forest resources of the world are located in mountainous regions, it is our belief that

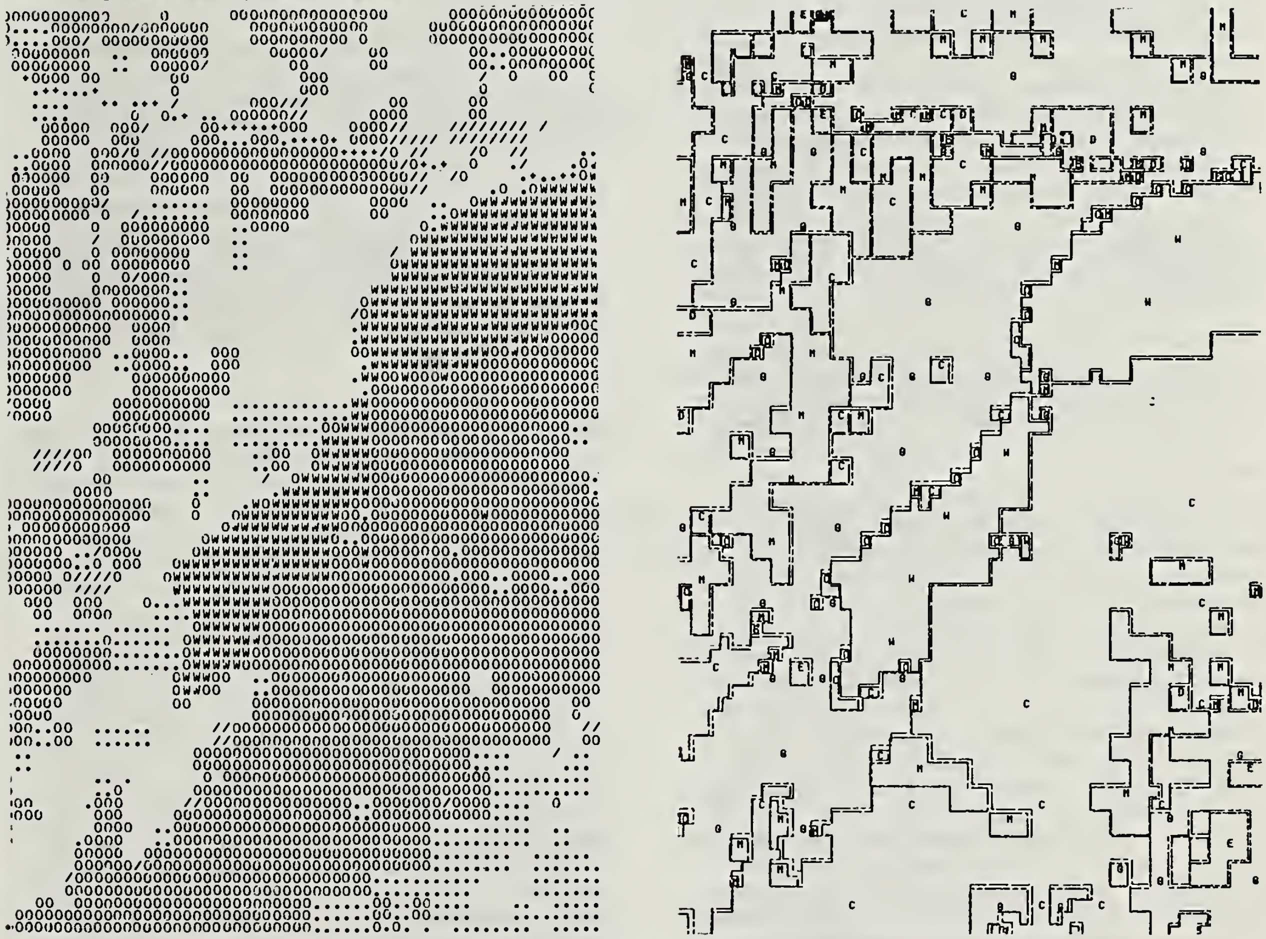

Figure 4a (left) and b (right). Two Different Types of Computer-Generated Classification Maps. A standard line-printer was used to obtain the map on the left whereas the map on the right was obtained by a Calcomp plotter. Both maps were generated using the same classification results data tape. O=Coniferous Forest, /=Deciduous Forest, W=Water, •=Exposed Rock & Soil, Blank=Grassland.

computer-aided analysis techniques must be tested in mountainous as well as flatland areas, if we are to determine the true practical capabilities and limitations of these techniques.

Most of our work has concentrated on the San Juan Mountain area of Colorado which contains a complex mixture of forest types, rangeland, alpine tunda, agricultural areas, water bodies, geological features and various manmade features. The topography of this test area is rugged, ranging in elevation from less than 2000 meters to over 4200 meters. Within this range of elevation, there is a distinct distribution of cover types according to altitude. Much of the area is dominated by ponderosa pine (Pinus ponderosa) forest, but Douglas fir (Pseudotsuga menziesii var. glauca), Engelmann spruce (Picea engelmanii), and subalpine fir (Abies lasiocarpa) are found at the higher elevations and on steep north slopes. There are also many stands of quaking aspen (Populus tremuloides), primarily on sites that have been disturbed by fire or avalanches. At lower elevations, the drier steep southern slopes are dominated by Gambel oak (Quercus gambelii), and the valley bottoms are occupied by agricultural land (mostly hayfields). Timberline in the region is at approximately 3600 meters, and extensive areas of tundra are found above this elevation.

One of the major studies in the San Juan Mountains utilized Landsat data to map and tabulate forest and other major cover types over a relatively large area of 993,800 hectares (2,456,000 acres). The Landsat data used had been obtained on Sept. 21, 1973. Sixteen training blocks were defined, each of which contained four to six different cover types. The location of these training blocks was based in part upon the availability of aerial photography for those particular areas, as well as the spectral heterogeneity of these blocks. The Multi-Cluster Blocks technique was utilized and each training area was clustered into 12 to 18 spectral classes. Spectrally similar classes were then combined, resulting in 14 distinct, separable spectral classes. Each of these spectral classes were identified using existing aerial photography and type maps of the area. It was determined that the spectral classes present could be grouped into five "Major Cover Types" or "Land Use" Categories[1], including Coniferous Forest, Deciduous Forest, Grassland, Water, and Barren (exposed rock, outcrops, soil, and sparsely vegetated tundra). The grassland category included both cultivated pasture and rangeland areas because they could not be reliably separated on the basis of spectral response.

[1]A combination of Level I and Level II Land Use Categories as defined by U.S. Geological Survey Circular 964 (Anderson et al, 1976).

Test areas which included a total of 16,170 resolution elements were then obtained from quadrangles in which no training blocks were located. Aerial photos and subsequent field checks were used to accurately identify the cover type and characteristics (e.g. stand density) of each test area. After the entire area was classified, a qualitative evaluation of the resultant maps indicated that the classification appeared to be reasonably accurate. To obtain a quantitative evaluation, the computer classification of the designated test areas was tabulated, the results of which are shown in Table 1.

This type of tabulation allows an effective method of evaluate both the inclusive and exclusive errors present in the classification, and to determine performance for individual cover types as well as for the overall classification. Table 1 indicates that a relatively accurate classification had been obtained for these cover types, using computer-aided analysis techniques and Landsat satellite data. This result was believed to be particularly significant in view of the topographic and vegetative complexity of the area, and the size of the test site involved.

To evaluate the classification using acreage comparisons, the number of resolution elements classified into each cover type within each of the 63 quadrangles (U.S.G.S. 7½ minute quadrangles) in the entire test were tabulated, and area estimates based upon the computer classification were obtained. A separate team of people utilized planimeters and dot grids to determine the area of the various cover types according to type maps which had been developed from aerial photos using standard photo interpretation techniques. A random sample of seven quadrangles (totalling about 112,400 hectares) were utilized for the photo interpretation acreage estimates. Comparison of these two data sets resulted in a correlation coefficient (r) of 0.97. Such a correlation coefficient would indicate that the area estimates obtained by computer analysis of Landsat data are in close agreement with the estimates obtained from aerial photos, thereby providing additional confidence in the classification accuracy.

A cost evaluation of this analysis indicated that the total cost (including computer, personnel salaries, etc.) for pre-processing, developing the training statistics, classifying the data, and evaluating the results was

Table 1 -- Classification Performance of Major Cover Types in the San Juan Mountain Test Site (993,800 hectares).

Cover Type	No. of Samples[1]	No. of Samples Classified as: Coniferous	Deciduous	Grassland	Barren	Water	Shadow[2]	Percent Correct
Coniferous	9,634	9,110	22	53	21	96	332	94.6
Deciduous	1,475	113	1,286	76	0	0	0	87.2
Grassland	3,677	49	129	2,988	510	0	1	81.2
Barren	35	0	0	1	34	0	0	97.1
Water	1,349	6	0	0	0	1,334	9	98.9
Totals	16,170	9,278	1,437	3,118	565	1,430	342	

Overall Performance = (9,110 + 1,286 + 2,988 + 34 + 1,334)/16,170 = 91.2%

[1]Each "sample" is a Landsat resolution element. The column labelled "No. of Samples" indicates the total number of resolution elements of the various cover types actually present in the test areas (assuming that each test area contains only a single cover type).

[2]One of the 14 spectral classes that had been defined involved areas of topographic shadows, but since this was not an actual cover type, any resolution elements belonging to this spectral class were considered as errors in the classification.

approximately \$0.0025 per hectare (0.1¢ per acre). Since this analysis was done on a medium-speed digital computer programmed for research types of activities, it would appear that in the future, such analyses could be conducted on special purpose, high speed digital computers in a relatively cost-effective manner.

Table 2 -- Classification Performance of Forest Cover Types for the Vallecito Reservoir Study Site.

Cover Type[1]	No. of Samples	No. of Samples Classified as: Pine	Spruce/Fir	Oak	Aspen	Grassland	Water	Barren	Percent Correct
Pine	1111	904	169	5	9	3	1	20	81.4
Spruce/Fir	747	254	485	2	6	0	0	0	64.9
Oak	481	8	0	297	95	81	0	0	61.7
Aspen	204	5	0	33	160	6	0	0	78.4
Grassland	242	2	0	6	0	232	0	2	95.9
Water	240	0	0	0	0	0	240	0	100
Barren	98	0	0	0	0	6	0	92	93.9
Totals	3123	1173	654	343	270	328	241	114	

Overall Performance = (904 + 485 + 297 + 160 + 232 + 240 + 92)/3123 = 77.2%

[1]Pine = Ponderosa Pine; Spruce/fir = Engelmann spruce, Douglas-fir and subalpine fir; Oak = Gambel oak, Aspen = Quaking aspen.

A second phase in the computer-aided analysis of the satellite data from this area involved mapping forest cover types over a more limited test site, referred to as the Vallecito Reservoir Study Site, which covered an area of about 23,000 hectares. The analysis procedures previously described were again utilized in this classification but since a more detailed level of classification was involved, a larger number of spectral classes had to be defined and utilized. In this case, a total of 24 spectral classes were obtained for the analysis. The computer classification of forest cover types resulted in a map of this intensive study site that qualitatively looked fairly good, but it was not as accurate as the map of major cover types. In several areas, individual forest cover types appeared to have been misclassified within the general categories of coniferous or deciduous. This was substantiated by a quantitative evaluation using test areas which had been carefully field checked. These results are shown in Table 2.

The results shown in Tables 1 and 2 indicated that a higher level of classification performance can be achieved for major cover types than for individual forest cover types. This is to be expected, since fewer and more easily separated spectral classes (i.e. major cover types) normally can be classified more accurately. In situations where there are larger numbers of spectral classes, (all of which are in the general category of "green vegetation"), the individual classes usually are not as spectrally separable and the resultant classification accuracy is generally lower. In this case, the 60-80% accuracy for the individual forest cover types probably is not accurate enough to be useful from a practical standpoint. However, preliminary results indicate that techniques which allow the use of topographic data in addition to the spectral data may enable the accuracy to be improved (Hoffer, 1975a). Additional work is needed to determine the level of detail that can be achieved and the conditions under which these techniques can produce satisfactory results.

In evaluating the specific reasons for classification errors within individual forest cover types, preliminary tests indicated that aspect, slope, elevation, and stand density all cause a statistically significant impact on spectral response (Hoffer, 1975b). A later more detailed analysis on the spruce/fir cover type has shown that decreasing stand density can be correlated quite well with increasing spectral response. Figure 5 shows this relationship for crown closures ranging from 0% to 100%, in 20% increments. The actual response values were slightly higher in the infrared than the predicted values which had been based on the assumption that the grass/forest mixture would produce a linear relationship between 0% grass & 100% spruce/fir and 100% grass & 0% spruce/fir. A similar relationship between spectral response and crown closure has been observed for three groupings of stand densities in southern pine by Williams and Haver (1976).

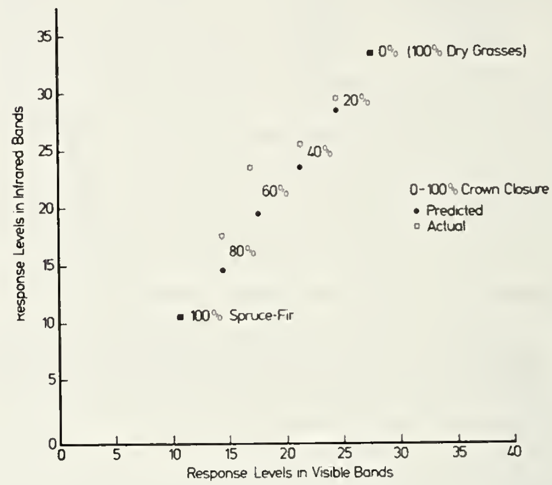

Figure 5 -- Spectral Response in Relation to Percent Crown Closure for the Spruce/Fir Forest Cover Type.

Analysis of Skylab MSS data produced results that are generally comparable to those obtained with the Landsat data. The data were obtained on June 5, 1973, and there was some snow present in the test site. Therefore, the classes defined and mapped included coniferous forest, deciduous forest, grassland, water, and snow. Even though the quality of the data was rather poor (i.e. low signal to noise ratio) the improved spectral resolution and spectral range of the Skylab MSS data (as compared to the Landsat data) enabled results to be obtained that were only slightly less accurate than those that had been obtained with the Landsat data. A classification performance of 85.1% was found for the major cover types, based upon a set of test data that included a total of 2400 pixels. The classification for individual forest cover types was 71.0%, again indicating the difficulty of obtaining highly accurate classifications for forest cover types in this area of complex topography.

Acreage estimates of major cover types obtained by computer-aided analysis of the

Skylab data were again compared to acreage estimates obtained by standard photo interpretation techniques, on a quadrangle-by-quadrangle basis for the five 7½ min. U.S.G.S. quadrangles in the test site. The photo interpretation was done by researchers at the University of Colorado, using 1:120,000 scale color infrared photos obtained the day after the Skylab MSS data were obtained. The result of this acreage comparison is shown in Figure 6.

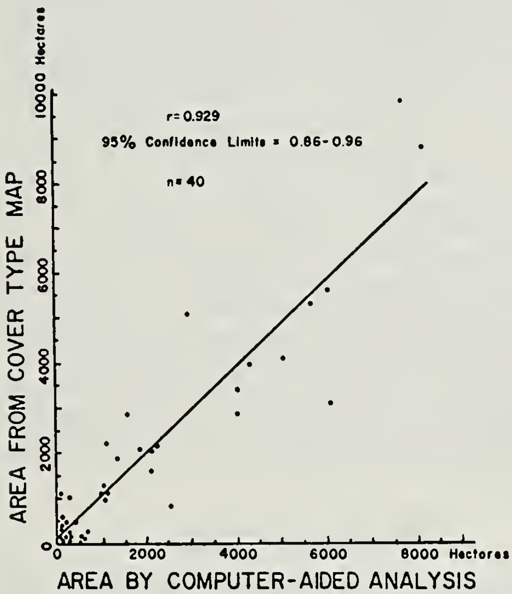

Figure 6 — Acreage Estimates of Cover Types Obtained by Computer-Aided Analysis of Skylab MSS Data, Compared to Aerial Photo Interpretation Estimates.

As was the case with the Landsat data, a high degree of correlation was again found between these two very different methods of obtaining acreage estimates (e.g. computer analysis of satellite data and human interpretation of aerial photos). Because of the statistical basis for the computer classification of the MSS data, a particular individual resolution element will have a certain probability of being mis-classified. However, over a fairly large geographic area such as a 7½ minute U.S.G.S. quadrangle, some inclusive and exclusive classification errors tend to balance out, thereby resulting in acreage estimates that are somewhat better than one might anticipate, given the classification accuracy achieved.

One of the most significant results of our work in this Colorado test site has involved the overlay of topographic data with the satellite data. The Defense Mapping Agency has utilized 1:250,000 scale U.S.G.S. topographic maps to digitize the elevation data, using approximately a 50 meter grid. A data tape containing this digital elevation data for the San Juan Mountains test site was obtained from DMA, and techniques were developed at LARS to digitally overlay this data onto the Landsat and Skylab MSS data. An interpolation procedure was then developed to define the aspect and slope of each resolution element.

The combination of cover type classifications plus elevation, slope, and aspect data in a computer-compatible format for this large area in the San Juan Mountains has enabled a very flexible and useful type of map output to be produced for resource managers. We have worked with U.S. Forest Service personnel involved in management and land use planning activities for this area, producing a variety of map combinations for their evaluation and use. In one case, for example, wildlife management personnel needed "big game winter range" maps of this area, on a quadrangle-by-quadrangle basis. In this case, big game winter range was defined as "grassland" cover (obtained from the computer classification of satellite data), for elevations between 7500 and 9000 feet, at slopes of less than 30°, and only for S.-SE. to S.-S.W. aspects. This combination of cover type and topographic characteristics was quickly and inexpensively displayed in map and tabular format and supplied to the Forest Service personnel in the form of 1:24,000 scale maps.

We believe that the speed and flexibility of being able to combine various cover type and topographic features has tremendous potential for the resource manager. Overlays of additional types of data, such as land ownership, political boundaries, soils data, etc. would allow data bases to be developed that would enable planners, resource managers, and others to obtain maps and tabulations of a wide variety of combinations of data. Such combinations could be defined by the user so as to meet a particular information need for a specific area. We believe that it is toward this type of system for data manipulation that we should be striving. Such systems could make use of computer-derived classifications of cover type (obtained from satellite data) as simply one part of the entire data set. The use of digital computer systems in such a manner would provide the resource manager with a flexible tool to meet his specific requirements for many types of information.

SUMMARY AND CONCLUSIONS

The application of computer-aided analysis techniques to satellite MSS data has shown that major cover types (such as coniferous forest, deciduous forest, grassland, exposed rock and soil, snow, and water) can be identified and mapped with a reasonable degree of accuracy (85-90%), even in areas of rugged mountainous terrain and spectrally complex vegetative cover types. Analysis of Landsat MSS data on a large (993,800 hectares) test site resulted in a classification performance for major cover types of 91.2%. (This figure is based upon the tabulation of 16,170 resolution elements from test areas that were carefully field checked and that had been designated in quadrangles other than those used for developing the training statistics.) Classification of Skylab MSS data resulted in a classification performance of 85.0% for the major cover types, which was somewhat less accurate than the Landsat classification, probably due to the poor quality of the Skylab data. The Landsat MSS data was also used to map individual forest cover types. The resultant 77.2% overall classification performance tends to indicate that results at this level of detail would probably not be accurate enough to provide useful information for most users. Further testing should be carried out in large test sites to determine if a satisfactory level of classification performance can be achieved for individual forest cover types in areas that are not as topographically or spectrally complex.

Acreage estimates of major cover types obtained by computer-aided analysis of Landsat and Skylab MSS data were compared to acreage estimates obtained by manual interpretation of 1:120,000 scale aerial photos. Five different tests were conducted, resulting in correlation coefficients ranging from 0.93 to 0.98. These results indicate that for fairly large areas, the analysis of satellite data by computer can provide acreage estimates that are very similar to those obtained by conventional techniques.

The development of the training statistics is a particularly critical aspect in the analysis process. A recently developed procedure for developing representative training statistics, called the "Multi-Cluster Blocks" technique has enabled significant improvements (e.g. 14%) in the final classification accuracy as compared to the "Supervised Training Fields" technique utilized by many analysts. Various types of output map formats can be produced from the computer classification tapes, including black and white or color-coded outputs, alphanumeric line-printer printouts, Calcomp plotter maps and others. These offer considerable flexibility in obtaining a format most suitable for meeting the particular needs of a user agency. The type of classification algorithm used can also enable different formats of classification maps to be produced. A newly developed "ECHO" algorithm appears very promising for forestry applications.

A particularly significant result of these studies involved the successful digital overlay of Landsat and Skylab MSS data with topographic data (elevation, slope, and aspect). Maps were generated on a quadrangle-by-quadrangle basis for various combinations of cover type, elevation, slope, and aspects, as specified by the resource managers and planners. Evaluation of these maps by the user agency (i.e., U.S. Forest Service) indicated that the results were adequate to meet many of their existing needs. Such a capability to combine the various features quickly and cost-effectively has tremendous potential. Overlay of additional data (e.g. soils, land ownership, political boundaries, etc.) would allow even more useful and flexible data bases to be developed. Such data bases, in combination with both existing and developing computer processing capabilities, will enable resource managers and planners to obtain map and acreage data on a custom-order basis, specific to their particular information needs. It is toward this goal that we must strive.

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An Evaluation of Small-Scale Color Infrared Photography for Integrated Resource Inventories[1]

Karl M. Hegg[2]

Abstract--The Resources Evaluation Unit at Juneau, Alaska recently completed an integrated inventory of 10 million acres in the Yukon-Porcupine Rivers area of Alaska using high altitude color infrared photography. The problems encountered and resolved in using high altitude photography for photo interpretation and fieldwork are discussed. Note is made of the difficulties in conducting a multiresource inventory involving several disciplines and agencies. The discussion concludes with comments on preliminary inventory results and with reccommendations for improving subsequent inventories of this type.

At this and other meetings, I have heard a half dozen different terms used to describe inventories of the total renewable resource base. Our Forest Survey group at Juneau first attempted such an inventory when we conducted a very extensive inventory of 229 million acres of interior Alaska from 1956-1961. We used high resolution 1:5,000 scale strip photography flown at 30-mile intervals, then photo identified, field sampled and reported on a wide range of forest and nonforest strata (Hutchison 1967, Hegg and Dippold 1971). In the more intensive inventories of 1967 and 1968, we collected wildlife browse data on forested lands. This browse data was tallied on a 1-milacre plot at each of our 10 points. We recorded understory vegetation by frequency, height classes or availability, and an estimate of use. But this and the extensive inventory data have not been interpreted or used by land managers. This illustrates what I see as a major shortcoming in any integrated inventory: the difficulty of involving land managers or being able to identify the specific data they need and obtaining the needed followthrough and feedback.

I do not know if this lack of feedback from management is a problem unique to Alaska, but for us the vast size of the State is probably a contributing factor. A land manager in Alaska talks in millions of acres, not thousands or hundreds of thousands. For example, Alaska's total land area is 362.5 million acres with 329.6 million of these acres in the interior section. This is equivalent to the combined areas of California, Nevada, New Mexico, and Arizona. The Bureau of Land Management, currently the prime land managing agency in Alaska, has this interior area divided into two districts and their personnel are thinly spread. Thus, they have had to operate mostly at a minimum care status, and this may be the major reason for our lack of feedback.

This low level of land management is reflected in the shortage of suitable resource photography. Considerable areas of Alaska were photographed with widely varying quality and coverage at 1:40,000 and 1:60,000 scales in the late 1940's and early 1950's. This was the extent of our photography until 1962 when more was acquired for the vicinity of Anchorage and Fairbanks by the Bureau of Land Management and the State of Alaska. From 1968-1972, through the interests of the Bureau of Land Management, the Bureau of Indian Affairs, the State of Alaska, and a grant from the Department of Commerce, we were able to obtain enough resource scale photography to keep an inventory program going through 1975. With the passage of the Alaska Native Claims Settlement Act in 1971, land ownership became very uncertain and the land managers were unwilling to invest in new photography. That left us with an inventory task covering 50 to 200 million acres, the size of the task depending on whether we continued normal forest inventory operations or tried to fill the needs of the Resources Planning Act.

In July of 1976, we were asked if we could inventory an area encompassing the proposed Porcupine National Forest in northeastern Alaska

[1]Presented at Society of American Foresters' Integrated Inventory Workshop, Tucson, Arizona, Jan. 8-12, 1978.

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with high altitude color infrared photography. This area is a part of the Yukon River basin where we had planned our next inventory effort; therefore, it seemed logical to at least try this photography. National Aeronatuics and Space Administration (NASA) flew the area August 27, 1976, taking about 3-1/2 hours to photograph 10 million acres. I have several contact prints and enlargements produced by the NASA photo lab on display.

For most of us in the Alaska Forest Survey project, this was our first exposure to color infrared imagery. One reads about the large increase in data when going from black and white to color, but the real benefit comes from the experience of working with this imagery. Even though these photos are at a 1:110,000 scale flown at 60,000 feet, they appear to have more potential in a multiresource inventory than has conventional photography. We have but one small complaint about the photographs: Since they were of an area mostly north of the Arctic Circle the fall color change had already started, the same vegetation type appearing in varying hues on the same flight line added to our interpretation problems.

After preliminary studies of the photos, we set up fairly elaborate interpretation strata of 13 nonforest categories including high and low brush, grassland; dry, mesic, and wet tundra, barren; and 6 water classes. The Yukon River basin is one of the greatest waterfowl producing areas of North America and we have conducted a trial study to identify sizes of several critical pond habitats. In the second stage of our two-stage sample, we checked the interpreter's size classification and measured the perimeter of a sample of the ponds. Through areal expansion of these measurements we provided the Fish and Wildlife Service with total acres and the associated perimeters of these ponds. They, in turn, can correlate this data with productivity by pond size, shoreline mileage, and topographic site.

We felt we could separate the forest-nonforest stratums consistently, but earlier experiences and a brief ground visit to the area in July 1977 convinced us that we would have problems with a commercial forest classification. We have a lot of forest land in Alaska that straddles the commercial forest land minimum of 20 cubic foot per acre mean annual increment. In the Yukon basin, where annual precipitation is 7-11 inches, this problem is compounded by fire. Our impression is that most of the Yukon area has been burned at least once--many areas several times--in the past 100 years. Fires remove the insulating moss and duff layer; decreased insulation drives the permafrost layer down, and a temporary one-cycle commercial site may be the result. This situation made us decide to measure all forest land and use our field data to establish area by productivity classes. Since forest land could be easily identified by hardwoods and conifers, we used that as a first break. We have had good results in stratifying by cubic-volume classes and thought it worth continuing on this small-scale imagery. We were able to identify consistently three volume strata for hardwoods and three for white spruce. White spruce, normally a commercial species in Alaska, generally occupies the better-drained sites while black spruce, normally noncommercial, occupies the wetter, less productive areas. Usually these site characteristics can be observed on air photos; this fact was used for a second break. We further classified black spruce into two volume classes giving us a total of eight strata in the forest land category. In addition, each photo point was coded for ownership, soil association, and aspect.

Our first look at this imagery also convinced us that we needed the magnification possible with the Bausch and Lomb zoom stereoscopes.[3] Since we were using continous roll positive transparencies in our interpretation, we needed an X/Y overhead carriage on our light table for stereo viewing. We were not ready to make a one-shot investment in all of this equipment and could not find it on loan so we made do with our Old Deflt Scanning stereo. The Old Delft has a maximum enlargement of 4-1/2 times. When we needed more magnification we inverted two 8-power lupes and obtained surprisingly sharp images. Meanwhile, we ordered auxillary 3- to 9-power eyepieces for the Old Delft which arrived on schedule at the end of our interpretation. They should, however, prove useful as we continue our inventories with this small scale imagery.

That was only part of our improvising. We also had to etch a very fine line grid as intersections for our photo interpretation points since a magnified dot-grid point would obscure too large an area. There were no readily available photo protractors for this scale photography, but we found that magnifying reticles were ideal for determining area and distance. We also modified an old hand-built light table that we find to be a better light source than many commercially models.

Our first real problem with high altitude photography came when we ordered stereo enlargements for use as field photos. Office use with optical magnification presented little problem. Film grain would appear only when magnification neared 20 times. We had the Agricultural Stabilization and Conservation Service lab at Salt Lake City run a series of enlargements at scales

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[3] The use of trade names or corporation names does not constitute an official endorsement by the U.S. Department of Agriculture.

of 1:11,500, 14,300, 18,000, 28,000. These enlargements and the 1:110,000 print are on display. We decided on the 1:18,000 as closest to our normal resource scale photos and regretted it. We now know that a 1:28,000 or smaller scale would have held more detail and with 4-time optical enlargement in the field have proved more useful. At the 1:18,000 scale we had trouble with colors melding into each other with only larger objects such as tree clumps or meadow-forest edges easily identifiable as starting points to plot locations.

As I mentioned earlier, we have been involved several times in trying to collect data on more than trees with a notable lack of success in obtaining an analysis of the data collected. Even though we recognized the potential of the color infrared photography, past experience and work pressure kept us from involving other agencies or disciplines in this inventory. It was a pleasant surprise to us when the Institute of Northern Forestry at Fairbanks, in cooperation with the University of Alaska, suggested additional field measurements of litter, moss, thickness of organic matter, soil temperatures, depth to permafrost, a listing of of understory vegetation types and their proportions, plus any observations that related to stand history. We had but assimilated this request into our data collection plans when the Soil Conservation Service asked to observe our sampling procedures and field methods. The result of this was an agreement that we would dig shallow, 18-inch-deep soil pits and follow accepted SCS practices to obtaining data needed to classify soils. (Bear in mind that most of Alaska has only preliminary soil surveys). The information thus collected would extend their knowledge and would reduce the amount of fieldwork in future soil surveys. Recent experience in trying to provide range data for the 1979 Resources Planning Act and SCS interest led to an arrangement where our field crews would use SCS methods in sampling range and woodland vegetation. These were superimposed on our regular inventory plots and additional plots were taken in nonforest areas while awaiting helicopter pickup.

At the conclusion of this inventory we will have provided field data for correlation studies to two divisions of the University of Alaska, the Institute of Northern Forestry, two divisions of the Soil Conservation Service, and selected areas for Doyon Limited (an Alaska Native Corporation) and for the U.S. Forest Service Forestry Applications Center (FAS) at Houston, Texas. The latter is ground-truth to help the FAS and NASA in their Ten-Ecosystem study. If this is not an integrated inventory, it is at least diverse.

We were not able to complete the Porcupine area inventory this past summer. A lack of financing, logistical problems of finding additional trained crews, and lateness of the season forced us to suspend operations in early September. North of the Arctic Circle fall and winter come early with the possibility of snowfall occurring anytime after September 1. While I cannot give a statistical analysis of our work with color infrared, I can note a few comments and recommendations obtained from experience. Our photo interpretation classification has generally been very good. We have been confused at times by spruce-hardwood and tree-brush mixtures accentuated by the seasonal change taking place at the time of photography, and by the changes in color balance across a photo, between photos, and between flight lines. Despite this, I believe we have done as well as on large-scale photography. We did vary widely on our tundra and grassland types. I believe this was due, in part, to inadequate criteria for recognizing these types plus seasonal changes. As an example, a greenish color with little observable texture was widespread in the area. We classed this as low bush because of site locations. Our classification was almost right, it was dead brush!

This past summer we ran several transects to obtain specific ground-truth across forest-nonforest conditions that should improve future classifications. We may consider even finer breaks since with photos in hand we were able to identify plant communities by species. On display are several stereograms we have prepared from these ground checks with corresponding aerial oblique and vertical views. An example of finer detail available is shown by the black and white enlargement of a meadow. Casual study would class this as grassland or dry meadow. There are actually three distinct grass and sedge communities that can be identified on the high altitude photo.

Our inventory of the Porcupine area using color infrared photography is not going to be a one-of-a-kind type. We now have on hand or have access to similar photography covering about 60 million acres in Alaska and are actively encouraging acquistion of more. We plan to continue the use of this imagery in our forest inventories and are cooperating with other agencies to extend the range of work. This year we are cooperating with the Soil Conservation Service and the Fish and Wildlife Service and the State of Alaska in a river basin study of the Susitna River Valley north of Anchorage. This will be an integrated inventory of timber, range, wildlife habitat, soils, and water. Our inventory of the Porcupine area was an operational task that left no time for any formal research of techniques. But the experience gained from this inventory is helping us in the Susitna area. We feel that there was considerable error in locating the exact same point on the ground that was interpreted on the aerial photo; consequently, this year we are seriously considering vegetation type maps. We would then be sampling within a typed area, and the exact plot location would not be as critical.

With this approach we reduce the problems of plot location and can then vary the sampling intensity for different objectives. This integrated inventory approach should alleviate a situation that has bothered me for years. In Alaska it has cost us as much as $450 to visit a plot location. It has not and does not make sense to visit an area only to measure trees without also looking at all of the other renewable resources.

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Vegetation Condition Estimates Using Color Infrared Aerial Photography[1]

Marshall D. Ashley, Daniel Corcoran and Louis Morin[2]

Abstract.--Natural resource managers are concerned with knowing vegetation conditions for many reasons integral to their job responsibilities. Described here are methods and techniques for assessing the condition of spruce-fir forests under intensive insect attack. Color infrared photography at scales of 1320 ft./in. and larger taken in late summer-early fall was found most useful in defining forests having various stages of feeding stress, recovery and mortality. The authors feel the techniques developed here are applicable to the study of other forest and vegetative conditions.

INTRODUCTION

Vegetation condition, whether it be forest, agricultural or range, is one of the prime concerns of the resource manager whose income or other benefits are tied with vegetation status. Present biomass, volume, growth rates and mortality data, along with a knowledge of present stress factors such as the intensity of insect attack, are primary components needed in the estimation of vegetation status.

As an example of how mortality and stress information may be gathered, this paper will describe work done by the authors on the use of aerial photography to assess the condition of eastern spruce-fir forests. The techniques described could be applied easily to the study of forest conditions in other parts of the country having different stand conditions.

The spruce-fir forest covers much of eastern North America and is one of the most valuable resources of the region because of its timber, recreational and other related benefits. Presently much of this forest is undergoing a massive infestation from the spruce budworm insect (*Choristoneura fumiferana*, Clem.) and private, state, provincial and federal natural resource managers throughout this area have become increasingly concerned with finding ways to monitor the condition of this forest (Balch 1952, Molnar 1975). Large chemical spray operations have been undertaken annually to prevent excessive tree loss from the insects' feeding and a system is needed to evaluate the success of this program, the consequences of where it isn't successful and the changes in forest condition where for biological, political or other reasons it is decided not to spray (Trial 1977). The authors suspect similar conditions and concerns exist in western North America.

Several researchers have proposed that aerial photography or other remote sensing imagery could provide a good, cost effective method of evaluating forest condition. Color and color infrared photography ranging from very small scale to large scale has been used successfully in detecting various forest disturbances and making estimates of forest condition (Aldrich 1975, Ashley 1976, Beaubien 1975, Beaubien and Jobin 1974, Ciesla 1974, Heller 1973, Meyer 1967, Rohde 1975). Many studies have been reported on how to estimate the volume of timber lost from insect or disease attack (Hamilton 1972, Rush 1977, Wear 1966).

As previously mentioned, the authors have

[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan. 8-12, 1978.

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been developing techniques for using aerial photography to estimate the condition of the spruce-fir forest. The work described here has been underway for the past five years and has been concerned with studying the best film, filter, scale and seasonal combinations for assessing budworm related forest status (Ashley 1976). Specifically research has been conducted on the use of color infrared aerial photography for identifying forests needing control measures to prevent excessive mortality, assessing the recovery of stands after spraying, estimating mortality trends and locating stands of dead timber requiring salvage. Indeed some of this work is beyond the research stage and is now in the applied realm--most appropriate for a workshop. While the emphasis of this work has been on the study of spruce-fir forests, the authors feel that many of the techniques and methodologies described here could be transferable to the study of vegetation condition in general.

DATA COLLECTION

Vertical color infrared photography (CIR), oblique color photography, laboratory and ground study data were used in this project to find how well the vertical photos could be used in the study of forest status. This data has been collected over the past four years on several sites having a variety of forest conditions. Included have been stands with little or no insect feeding, moderate to severe current or past defoliation, scattered to high mortality from feeding, and those showing recovery in varying degrees from spraying. Figure 1 illustrates the appearance of trees having these conditions. The photography was flown in the summer when the budworm clipped needles were at the height of browning, where feeding was taking place, and in early fall after these clipped needles had fallen from the branches.

The vertical CIR (Kodak film type 2443) photos were taken with several camera, filter and scale combinations. Two Hasselblad 500 EL cameras having a 70mm format and focal lengths of 50 or 80mm and a Zeiss RMK A21/23 having a 229mm format and a 210mm focal length were flown. Two filters were used in exposing the CIR film, one equivalent to a Wratten 12 and the other to a Wratten 15. Table 1 summarizes the vegetation conditions, seasonal and scale characteristics of the imagery.

The oblique color photography was obtained to verify the vegetation condition at the time the vertical photos were flown. These were taken from low level flights using a Nikon F-2 camera and Ektachrome-X slide flim.

The laboratory and ground studies of the photography were made using standard photo interpretation equipment and techniques. Pocket stereoscopes, mirror stereoscopes and Bausch and Lomb 7-30X stereoscopes were utilized for studying the photos in stereo and a 7X hand magnifier was used for monoscopic study. Transparent acetate overlays were employed to cover the CIR imagery and any notes or points of interest from the interpretations were marked directly on these overlays.

Extensive ground truthing was made of all interpretations. Some ground and photo interpretation comparisons were used for training purposes and then ground checks were made of subsequent interpretations to judge the consistency and accuracy of the photo work.

METHODS OF EVALUATING FOREST CONDITIONS

The evaluation of the CIR photography for vegetation condition assessments was done in several phases. Earlier projects had taught the investigators to go through a series of lab and ground comparison work for training purposes and then when confident of their interpretation abilities to do some operational type trials.

The evaluation of stand condition followed this pattern of lab and ground comparisons. Selected stands having coverage at all scales were studied in the lab and the field, and any image characteristics, such as color, which might be indicative of the forest's condition were noted. Testing was also done to examine the relative merits of stereo versus monoscopic viewing at the different magnification powers of the occulars.

For the spray recovery assessments the CIR photos were studied in the lab in stereo and monoscopically under 2X and 7X magnification to find if there were image features which would be representative of good to poor recovery. The imagery was then taken to the field and checked for interpretation accuracy. Entomologists responsible for collecting ground data to evaluate the spray's success accompanied the photo interpreters on some of the ground checks. The work was done using only the 825 ft./in. scale because the state entomologists that are using recovery data felt that individual trees or small groups of trees should be identifiable with the ability to collect information on them and this was the only scale where individual trees could be resolved with any consistency.

The study of how well individual dead trees and stands needing salvage could be detected started on an experimental basis,

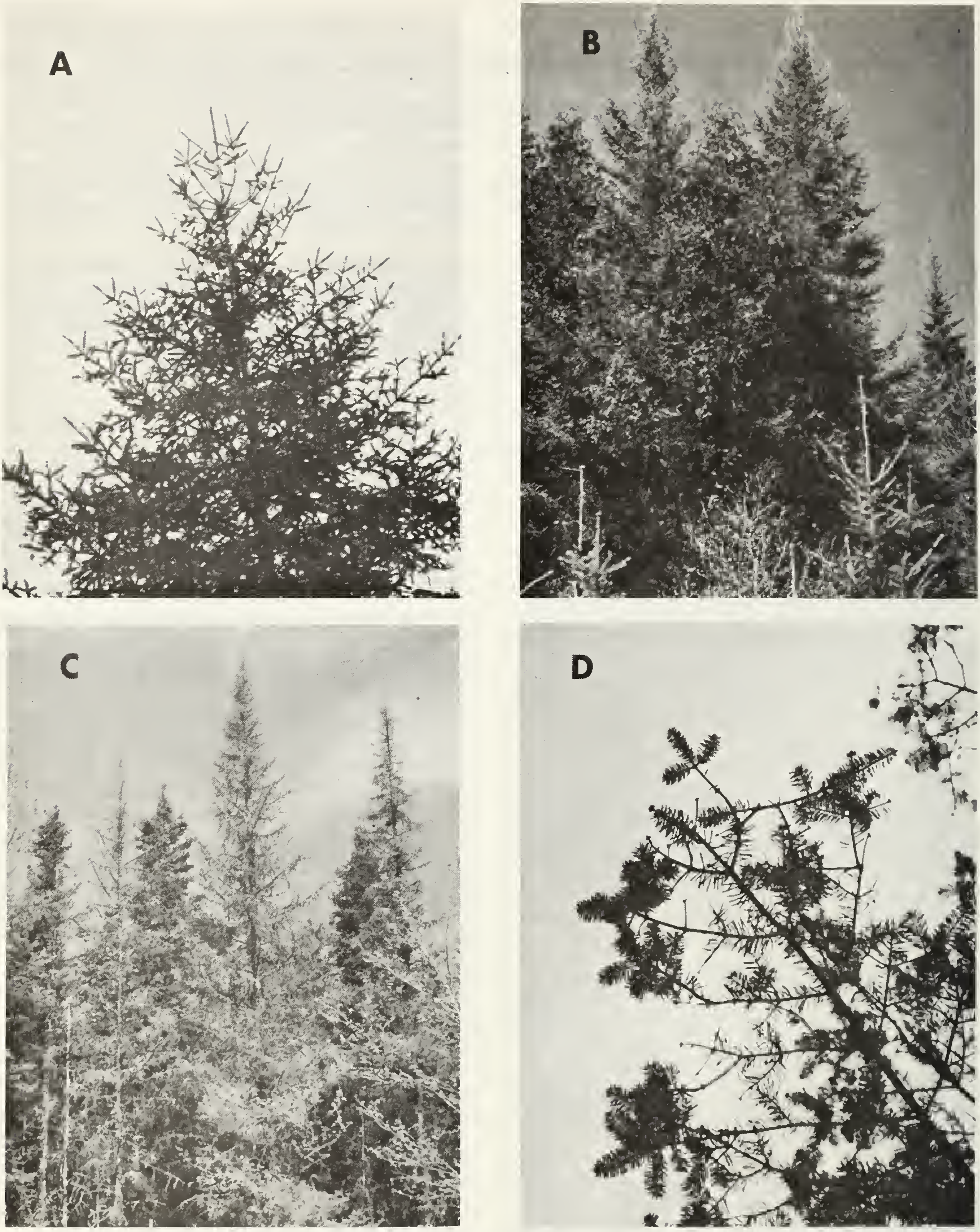

Figure 1.--Tree conditions resulting from feeding by spruce budworm; 1A-trace current feeding, 1B-heavy current and past defoliation, 1C-mortality of balsam fir, 1D-recovery from heavy past feeding.

scales, areas having mature stands often had a grayish-dark appearance even when there hadn't been any insect feeding. This was likely because internal stand shadowing dominated the scene.

The recovery of stands from successful spray applications was also readily detectable. On the CIR film, for summer or fall and either filter, the pinkish-orange of those crowns having new branch tip growth could accurately be discerned from those crowns where, because of dead twigs or continued feeding, the crown had a grayish-brown appearance. Difficulty was noted, however, in assessing individual trees if the stand density was high or if the tree was not at or above the average level (height) of the stand crown canopy. While not proven as significant in influencing the accuracy of interpretations, several factors were at least subjectively desirable to the interpreters. Generally they preferred the fall imagery taken with the Wratten 12 filter. They also preferred stereo viewing at 2X or higher magnification. The stereo viewing tended to balance out shadow problems. The one negative aspect of the results was that the degree of recovery couldn't be quantified beyond saying there was or wasn't new foliage growing.

The work on following changes in forest condition reflected by significant changes in mortality on areas having insect stress over time hasn't progressed through multiple years of data so that any proven conclusions about the utility of the method can be stated. From the ANOVA the only significant difference was between the number of trees having crowns greater than ten feet in diameter and those having a lesser diameter. Since the areas where these plots were taken will likely continue to be infested in the near future, it will be quite valuable to compare their future mortality with this year's data where there were no significant differences in mortality between sprayed and non-sprayed sites.

The use of CIR aerial photos at a scale of 1320 ft./in. for locating stands needing salvage or presalvage is now being used on an operational basis. The location and size of these stands is being obtained from the photos and this data is being used to formulate harvesting plans based upon the stands' priority for salvage or presalvage. Such planning has helped reduce timber losses by concentrating the harvest in the most seriously damaged areas. The photography has also been of tremendous value in coordinating harvesting activities, particularly in positioning road systems into these areas. Figure 2 shows an area after salvage.

Figure 2.--A salvage operation in spruce budworm damaged stands.

The heavily damaged stands were most readily identified using late summer or fall imagery, after current defoliation wasn't a confounding factor in the tree's appearance. Stereo viewing at 2X magnification was found satisfactory for making these interpretations.

No attempt was made to estimate volumes from the photos, but the delineated heavy damage areas were transferred to type maps from which volume estimates were obtained. Ground inventory cruises were then made to verify the operability of those stands having an estimated volume great enough to justify salvage.

DISCUSSION AND CONCLUSIONS

The title of this paper implied a discussion of how to evaluate vegetation conditions in general. However, the methods and techniques described here have been for assessment of spruce-fir forest condition. The authors feel what was presented here is also applicable to the study of other forest and vegetation conditions. The most important part of this work in a practical sense is for one to comprehend the ingredients for success in studying vegetation condition using aerial photography as described in the methods and results section of this paper. These include synchronizing the timing of the photos to the condition you wish to study, have a scale large enough to resolve what it is you want to see, and most importantly, depending on how well the interpreter knows the ground and vegetation conditions in the area he is studying, allow a relatively large amount of time for training interpreters using ground truthing-photo comparisons.

Table 1.--Stand condition and aerial photography scale combinations

Timing of Photography	Condition of Spruce-Fir Foliage, if Damaged	Scales of photography for each flight: Feet/Inch	Representative Fraction
Summer	Height of browning of insect clipped foliage, needles still retained on the tree	2640	1:31680
		1320	1:15840
Fall	After clipped needles have fallen, only bare twigs and undamaged foliage remaining	825	1:9900

which has now gone operational. Data covering all scales, viewing techniques and different interpreters was collected and an analysis of variance run to find which factors most influenced the accuracy of mortality counts made on the CIR film. In conjunction with this test a series of ground plots were examined to find how much mortality was being missed on the photos.

As a follow-on to this work, a study has been initiated to find if mortality counts on 825 ft./in. CIR imagery can be used to document what happens to forests that by present judgement standards should be treated and in the future some are and some aren't. One set of photos have been taken on twenty-six areas representative of the two forest conditions and the visible dead crowns on two hectare plots (at average photo scale) tallied. For possible later volume analysis the tallies have been separated for crowns greater than ten feet in diameter and those less than ten feet. An analysis of variance (ANOVA) has been run to find if there were any initial significant differences between the treatments or in mortality by crown width. Since only one year of data has been collected, no comparison of mortality trends has been attempted.

The testing of how to locate dead or nearly dead timber requiring salvage or presalvage was done on an operational basis using 1320 ft./in. Zeiss photography. Industry foresters trained through workshops and ground evaluation of their own CIR photography delineated stands having moderate and heavy past feeding, and areas which they felt had enough mortality to warrent salvage. Following this low level aerial and ground surveys were made to evaluate the interpretation accuracy and operability of these areas.

RESULTS OF THE EVALUATION

The methodology and techniques reported in this paper were developed for the evaluation of spruce-fir forest condition. However, these and the results decribed here should be applicable to the study of other forest types and possibly vegetation in general.

Stands requiring spraying or other control measures were interpretable on the CIR photos. Acceptable accuracy was found when using the fall imagery at a 1320 ft./in. or larger scale, photographed using either filter and viewing at any of the magnifications in mono or stereo. Those stands where the trees had essentially two or more feet of bare tops and more than two years of feeding appeared grayish-brown as opposed to trees with lesser feeding which had a pinkish-orange color. Those forests in need of treatment from severe backfeeding resulted in several feet of near bare top and were identifiable by the high proportion of defoliated (gray look) crown in comparison with the undamaged foliage (pink look) with the stands.

Several interesting interpretation techniques and factors influencing interpretation accuracy evolved from this study. Summer imagery wasn't found useful because current feeding where it was taking place masked the appearance of previous feeding and the overall condition of trees. Monoscopic 7X viewing of the outer portion of the transparencies on the backlighted side of the frames often gave more accurate results. A highlighted tree periphery is viewed on this portion of the imagery because of the relief displacement and the tree's own shadow. Stereo viewing was necessary however, when the sun angle was low and seemed to balance out excessive shadowing between trees on a single frame. Smaller scales than 1320 ft./in. didn't allow reliable mapping of those forests needing treatment. At smaller

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Application of MSS Systems to Natural Resource Inventories[1]

F. G. Sadowski, W. A. Malila and R. F. Nalepka[2]

Abstract.--A recent investigation has shown that several factors can have important implications for the use of multispectral scanner (MSS) data in support of forest resource inventories. The results show that the accuracy for classifying forest features is greatly dependent on the spatial resolution of the data, the level of detail desired, and the processing technique employed.

Spatial resolution exerts a large influence on the amount of scene variance that occurs in data collected by MSS systems. By virtue of averaging information over larger ground areas, MSS data of coarser resolution has reduced variance which is shown to result in improved classification performance. Thus, spatial resolutions of the size provided by satellite MSS data may be most appropriate for some types of forest surveys.

Desired level of detail affects classification performance in that improved classification performance occurs for hierarchies of more general forest features. Results illustrate why MSS systems can provide higher levels of accuracy for large-area reconnaissance surveys dealing with generally-defined features than for detailed inventories of more specific features.

The application of different specialized processing techniques can dramatically improve classification performance. Multi-element classification appears to offer a definite advantage for improving classification of forest features in data having spatial resolution comparable to the present Landsat and proposed Thematic Mapper MSS systems. For fine resolution data, a two-stage proportion-space classification approach can provide accurate classification of forest features while additionally providing information on forest canopy spectral components that may be of use for intensive forest management efforts.

Through consideration of these factors, guidelines can be developed to assist forest managers in selecting appropriate remote sensing data acquisition and processing procedures. Use of such guidelines should maximize the benefits of remotely sensed information for specific situations.

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Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Jan. 8 - 12, Tucson, Arizona.

[2]Environmental Research Institute of Michigan, Ann Arbor.

INTRODUCTION

Since the initial development of the multispectral scanner (MSS), numerous experimental and semi-operational studies have addressed the applicability of MSS systems to natural resource inventories. Indeed, such studies have illustrated many of the inherent advantages that MSS systems have to offer as a tool to aid resource inventories. However, out of all such studies have come too few guidelines to assist resource managers in specifying parameters that will maximize the classification performance of MSS data for specific situations. It would seem that fundamental capabilities and limitations of MSS systems for resource inventories are not yet completely understood.

The issue of spatial resolution serves to illustrate the situation. The capability currently exists to acquire and analyze MSS data of forested regions for a wide range of spatial resolutions. Landsat MSS data are among the coarsest in resolution while increasingly finer resolution can be provided by MSS systems mounted in high and low flying aircraft. The resource manager might justifiably ask the question: "Which spatial resolution is optimal for classifying features of interest in forest resource surveys?" To help answer the question, one must determine in a systematic fashion the manner in which spatial resolution affects the classification of forest features. However, the vast majority of MSS data applications studies have utilized data for a single, specific case of spatial resolution in conjunction with a readily available conventional processing technique in order to obtain a specific level of information about a particular set of terrain features. Inconsistent combinations of these various parameters associated with each study and its respective data set have contributed to varying results, making the influence of a specific parameter (like spatial resolution) on forest and range feature classification difficult to determine. Resource managers may thus be left bewildered when trying to select appropriate MSS data acquisition and processing strategies.

This paper presents a discussion of three factors that have large influence on the classification performance obtained from data collected by MSS systems in support of forest resource inventories. These factors include:

- spatial resolution of the data
- level of information desired from the data
- processing technique employed on the data

Since these factors are subject to some degree of user specification (within the range of presently known or available technology), an understanding of them should begin to provide the basis for establishing guidelines that will enable resource managers to make better decisions about the use of MSS systems as a tool for natural resource inventories.

This paper does not advocate the use of MSS systems to the exclusion of more familiar or available remote sensors (e.g., aerial cameras). Many objectives of resource inventory or analysis can be better accomplished (e.g., more accurately, more economically, or both) with other sensors that might be employed from the air or on the ground. However, MSS systems possess some inherent properties which for some situations may make their use more desirable, perhaps even required for resource inventory or analysis. These properties are briefly summarized at the outset in order to establish the basis for further consideration of some factors that influence MSS data classification performance.

MSS SYSTEM PROPERTIES OFFERING POSSIBLE ADVANTAGES FOR RESOURCE INVENTORY AND ANALYSIS

MSS systems provide electronic recording and transmission of data. This makes them especially appropriate for unattended use in satellites where, by virtue of orbit configuration, they can provide repetitive coverage at regular intervals on a continuous basis. Thus, MSS systems can supply data required for large area surveys in a short period of time. They also enable repetitive update of temporal situations that require continuous monitoring such as insect and disease damage, deforestation, etc.

MSS systems provide data in a format readily amenable to computer analysis or image production. The computer-compatible tape format permits a rapid (potentially real-time) and precise means of data analysis that sophisticated users can utilize to improve the timeliness of their information. On the other hand, the production of images is particularly important for developing countries of the world where manual image interpretation procedures frequently represent the only means of data analysis.

Another major advantage of MSS systems lies in their provision for simultaneous recording of wavelengths of data that are both within and beyond the capabilities of camera systems. The acquisition and subsequent availability of data from the ultra-violet, visible, near-infrared, and thermal infrared wavelength

regions thus provides greater opportunities for multispectral discrimination of features.

Finally, and perhaps most importantly, MSS systems provide data already in a cellularized format that facilitates the orderly storage of their information content, the combined use of ancillary information for classification, and spatial analyses of the data. The Environmental Research Institute of Michigan (ERIM) is conducting studies that illustrate these advantages. For example, a generalized geographical information system was devised which could both facilitate the incorporation of MSS data and accommodate expected U.S. Forest Service system requirements [1]. In addition, the use of ancillary terrain information such as elevation, slope, and aspect as additional channels of data merged with MSS data has been shown to be useful for normalizing Landsat signal variations in mountainous terrain, thus improving classification performance of the data [1]. Also, a model has been developed to assess several spatial relationships of terrain features in classified MSS data and automatically determine a quality rating for wildlife habitat on a parcel by parcel basis [2].

FACTORS THAT INFLUENCE MSS DATA CLASSIFICATION PERFORMANCE

Spatial Resolution

Recent preoccupation with Landsat data by a large number of users has begun to accumulate a large volume of experience regarding the capabilities and limitations of coarse resolution satellite data. Results of some studies have speculated about the merits of finer spatial resolution; in particular, its influence on classification results. ERIM recently completed a study of the effect of spatial resolution on the classification accuracy of forest features using a commonly-applied conventional multispectral processing technique. A summary of the approach and results of that study is provided here, with complete details contained in References 3-6.

The MSS data set utilized for the study included 11 spectral channels collected by a multispectral scanner from an altitude of 610 meters (2000 feet) over the Sam Houston National Forest in east Texas. The data included approximately one million resolution elements, providing ground area coverage illustrated in Figure 1. Forest features, identified according to existing U.S. Forest Service timber stand maps, are listed in Table 1.

The inherent spatial resolution of (2 meters)^2 for this data set was degraded in successive steps to simulate five additional

FIGURE 1.--FOREST FEATURES IN MSS DATA, SAM HOUSTON NATIONAL FOREST (TEXAS)

TABLE 1.--FOREST FEATURES FOR WHICH CLASSIFICATION PERFORMANCE WAS DETERMINED IN THE SAM HOUSTON NATIONAL FOREST (TEXAS)

1	Shortleaf Pine Sawtimber - Immature
2	Shortleaf Pine Sawtimber - Mature
3	Loblolly Pine Sawtimber - Immature
4	Loblolly Pine Sawtimber - Mature
5	Loblolly Pine - Seedling and Sapling

data sets having $(4)^2$, $(8)^2$, $(16)^2$, $(32)^2$, and (64 meters)^2 spatial resolutions. This produced a total of six data sets that provided common ground area coverage for several cases of spatial resolution that varied from minimum areas small enough to resolve individual components of forest stands to areas large enough to approximate the coarse resolution of the present Landsat systems.

All data sets of varying resolution were processed with a conventional supervised classification procedure that utilized signatures extracted from training sets inside each forest feature. Signatures for these features were extracted anew for each data set from training

sets that covered equivalent ground areas in each case of spatial resolution. The ERIM linear decision rule was used to classify all resolution elements on an element by element basis into the respective signature distribution or an unclassified category. Results were tallied to provide the percent correct classification achieved within each feature. The percent of all resolution elements correctly classified in each data set was calculated to provide an overall classification accuracy.

Figure 2 illustrates that overall classification performance improved as spatial resolution was degraded from $(2m)^2$ to $(64)^2$. Such improvement in performance is attributed to a reduction in scene variation that is inherent in the averaging of information over larger ground areas. This result is best illustrated in Figures 3 and 4 where, for two dimensions, the signature distributions for features are shown at resolutions of $(2)^2$ and $(32\text{ meters})^2$, respectively. [In tests of spectral channel performance, the two spectral channels illustrated in these figures, namely the red (0.65-0.69 μm) and near-infrared (0.95-1.03 μm) regions, had proven to be among the best for separating the features.]

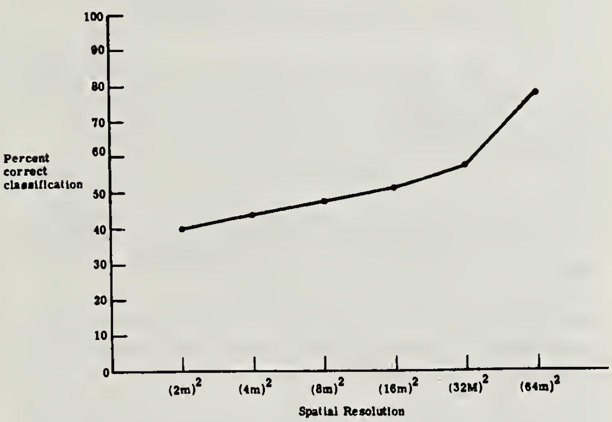


FIGURE 2.--CLASSIFICATION ACCURACIES FOR FOREST FEATURES GENERALLY IMPROVE WITH COARSER SPATIAL RESOLUTION WHEN CONVENTIONAL TECHNIQUES ARE UTILIZED

At $(2\text{ meters})^2$, the largely overlapping signature distributions obviously offered the least likelihood for successful discrimination of features. The large variance for each signature provides evidence of the spectral nonhomogeneity within the training areas, and the small mean separation among the signatures indicates many similarities among the data values of resolution elements in all training areas.

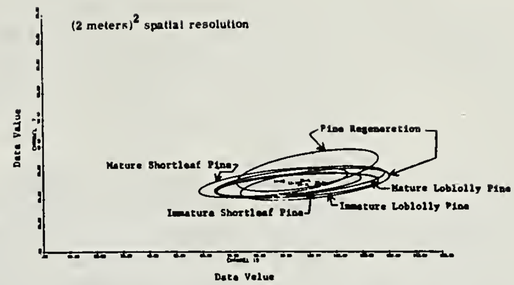


FIGURE 3.--SIGNATURE DISTRIBUTIONS FOR FEATURES IN $(2\text{ METERS})^2$ RESOLUTION DATA

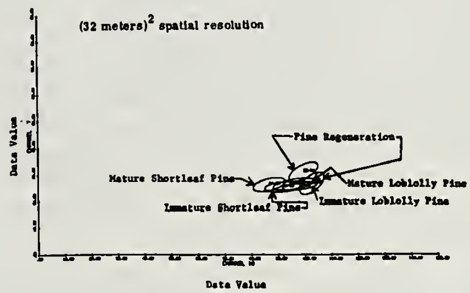


FIGURE 4.--SIGNATURE DISTRIBUTIONS FOR FEATURES IN $(32\text{ METERS})^2$ RESOLUTION DATA

Thus, misclassifications of those elements by the resulting signature set will be high. As resolution was degraded, the variance of each signature became smaller while the means for the most part remained unchanged, causing the amount of statistical overlap (competition) among the signatures to decrease. Thus, resolution elements in coarser resolution data should have higher probabilities of being correctly classified.[2]

The results in Figure 2 apply for training sets from which the signatures had been extracted. By showing classification performance

[2] When resolution was coarsened to $(64\text{ meters})^2$, an insufficient number of resolution elements prevented computing a valid signature for the Immature Loblolly Pine feature. Thus, the abrupt increase in classification accuracies that occurs from $(32\text{ meters})^2$ to $(64\text{ meters})^2$ in Figure 2 is due in part to the absence of a competing signature during the classification of the data, again causing resolution elements to have high probabilities of correct classification.

for training sets, we represent an upper limit of performance that assumes each feature area is adequately described by its respective signature(s). Classification performance decreased somewhat when accuracies were computed over the entire area of each feature. Such decreased performance is attributable to greater percentages of misclassified resolution elements and can be caused both by the increased variance in data values, not completely represented by the feature training set, that results from nonuniformities over the entire feature and the effect of boundary elements around the perimeter of each feature.

Figure 5 compares the overall classification performance for training sets to the lower performance achieved for total feature areas with and without boundary elements. In general, the decrease in classification performance from training sets to feature areas without associated boundary elements becomes greater in coarser resolution data. The impact of included boundary elements serves to further reduce classification performance as spatial resolution degrades, owing to the increased ratio of boundary elements to total feature elements.

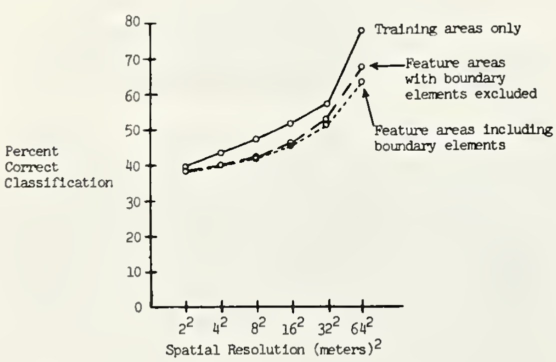


FIGURE 5.--COMPARISON OF CLASSIFICATION PERFORMANCE FOR TRAINING SETS WITH THAT OBTAINED FOR TOTAL FEATURE AREAS

In summary, these results illustrate that spatial resolution exerts a large influence on the amount of scene variance that occurs in data collected by MSS systems. By averaging information over larger ground areas, MSS data of coarser resolution has reduced variance. When classified with a conventional processing technique, coarser resolution data can ideally provide improved classification performance. However, due to the overall reduced variance in coarser resolution data, nonuniformities within terrain features will have a greater impact on reducing classification performance. Such nonuniformities could be attributable to occasional canopy openings, pockets of dead or dying timber, variable tree spacing, etc., within forest features. This suggests that careful consideration needs to be given to defining training statistics for features of interest in coarser resolution data. Additionally, the detrimental effect of boundary elements increases in coarser resolution data.

The implication for resource managers utilizing conventional data processing techniques would seem to be a recommendation to use MSS data sufficiently coarse to still provide acceptable location and mensuration accuracy. The physical and economic realities of processing data support such a recommendation. Thus, feature size and shape become the critical determinants for specifying a particular size of spatial resolution. For example, boundary elements in Landsat data could substantially reduce the classification performance for small woodlots in the midwestern U.S. However, their effect would be negligible when classifying features of large areal extent such as may occur in extensively forested regions. This suggests that spatial resolution of the size provided by satellite MSS data may be most appropriate for such surveys.

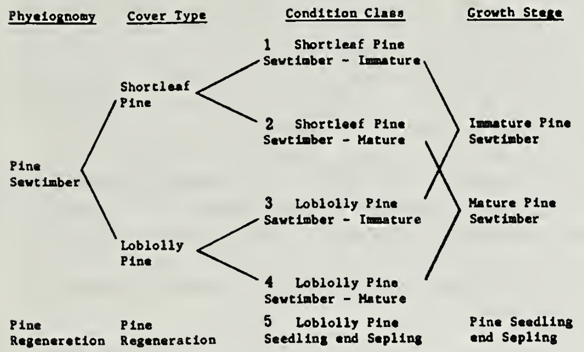
Level of Desired Information

In the preceding section, classification performance was cited for a set of five features that represented a very detailed level of classification. Each feature was a timber stand differentiated as to species, age, and size class -- i.e., condition class. The attempt to discriminate such specific features resulted in the small mean separation noted among the signatures in Figures 3 and 4. If the level of desired information were not so specific, one might expect greater mean separation among the signatures and thus better classification performance.

To illustrate the effect of different levels of classification, the classification results of Figure 2 were aggregated to provide a measure of classification performance for features of more general hierarchies (Table 2). Condition classes were combined into cover types on the basis of species (pine regeneration was retained as a separate feature), and alternately, into features based on maturity that we called growth stages. For the most general hierarchy, all pine saw-timber features were combined into a single physiognomic class to be compared with pine regeneration.

Figure 6 illustrates that classification accuracy was substantially higher for hierarchies of less specifically defined features.

TABLE 2. MANNER IN WHICH FEATURES WERE AGGREGATED INTO MORE GENERAL HIERARCHIES



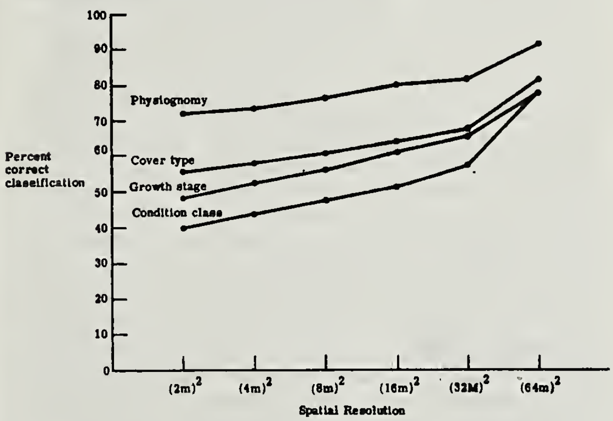


FIGURE 6. CLASSIFICATION ACCURACIES FOR ALL HIERARCHIES OF FOREST FEATURES

In other words, improvement in performance occurred as a result of aggregating the classification results of specific features into more general features. For each general feature, previous misclassifications of resolution elements among its specific features were properly counted as correct classification, reducing the total amount of misclassified elements for the respective hierarchy. Thus, the overall accuracy for classifying the physiognomic hierarchy of forest features is higher than for hierarchies of more specific classes -- a not-surprising result.

Because of substantially better classification performance for more generally-defined features, resource managers might be advised to avoid discriminating too specific features with MSS data when processed in a conventional fashion. In other words, MSS data processed with conventional processing techniques may be most appropriate for large-area reconnaissance surveys that typically deal with more readily discriminable features.

Processing Technique

Up to now, classification performance achieved with MSS data was shown to improve gradually but consistently with degraded spatial resolution for each level of desired detail. These trends place emphasis on the designation of readily discriminable features in coarse resolution data in order to achieve highest classification performance. Recent developments at ERIM illustrate that the application of specialized processing techniques can materially improve classification performance for both coarse and fine resolution data, and thereby possibly influence the level of desired information derivable from MSS data. Thus processing techniques could influence the utilization of MSS systems for particular applications.

Technique for Coarse Resolution Data

The previous application of a conventional multispectral processing technique to varying cases of spatial resolution resulted in higher classification performance for coarser resolution data -- apparently due to the reduced variation in the scene that occurs by averaging information over larger ground areas. For a resource manager using a particular case of spatial resolution, the degradation of resolution to obtain better classification performance may not likely be a practical procedure, nor one within his capability. In addition, there will be a limit to which data spatial resolution can be coarsened and still be useful for providing other aspects of scene information such as locational accuracy or accurate area measurement capabilities. However, multi-element classification rules offer the potential for providing the improved classification performance of coarser spatial resolutions while preserving the location and mensuration capabilities of finer spatial resolutions.

Conventional multispectral classification rules are based on information from one resolution element at a time. Multi-element rules differ in that they use information from groups of resolution elements when classifying a specific element. The so-called "nine-point" rules developed at ERIM [7] determine the classification of a resolution element on the basis of information from that element and its eight immediate neighbors. Such use of proximity information attempts to improve classification performance by incorporating the likelihood that a resolution element represents the same scene

class as its neighbors. Multi-element rules thus provide for the averaging of information over larger ground areas in a fashion somewhat analogous to the coarsening of spatial resolution. The influence of neighboring elements can be varied with the selection of a particular rule.

Four such rules were tested for their effectiveness in improving the classification performance of the (32 meters)^2 data illustrated in Figure 5 [4]. All four multi-element rules showed improved performance over the classification results achieved with the single-element rule for (32 meters)^2 data. For the most detailed hierarchy of features (condition classes), classification accuracies ranged from 13 to 25 percent better (Figure 7). Three of the rules showed performances that were higher than the single-element classification results achieved for (64 meters)^2 data. Thus, it appears that judicious selection of a multi-element rule can offer improved classification performance that is greater than an improvement that might be realized with standard classification procedures used on coarser resolution data.

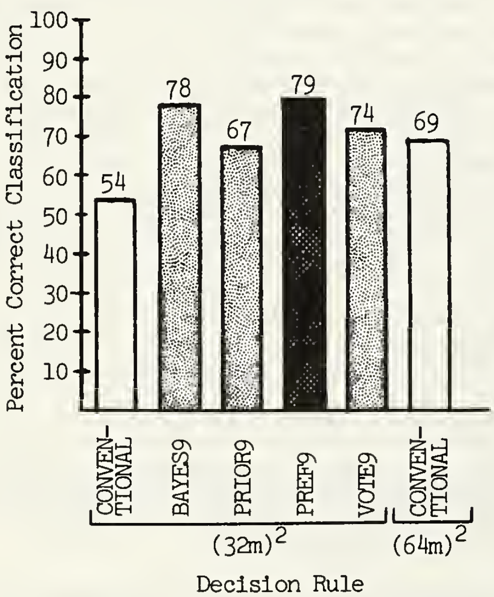


FIGURE 7.--COMPARISON OF OVERALL CLASSIFICATION PERFORMANCES ACHIEVED FOR THE CONDITION CLASS HIERARCHY OF FEATURES. Results are for total feature areas with boundary elements excluded.

Of the four multi-element rules, classification results were always highest for PREF9. This rule uses as its decision criterion the average, over nine elements, of the posterior probability of a feature at each resolution element. Comparison of these results with the results of the single element rules indicates that the increase in accuracy is largest for the hierarchy of condition classes, with lesser increases in performance noted for hierarchies of more general features. This trend suggests that when classification accuracy is low using standard techniques, specialized processing techniques give more improved accuracy than when accuracy is high with standard techniques. Thus, multi-element rules appear to be especially advantageous for improving the classification of detailed features that may be desired of forest surveys using coarse resolution satellite data.

Technique for Fine Resolution Data

The prior emphasis on coarse resolution data should not be construed as a case against the use of fine resolution MSS data. As a matter of fact, the presence of large signal variations in fine resolution data provides detailed information, not available in coarse resolution data, that may be of use for intensive forest management efforts. However, a conventional processing technique was shown to result in poor classification performance because of the large variance associated with signatures in fine resolution data (Figure 3). These large variances were caused by the wide range of spectral variation with each feature area that resulted from individual resolution elements falling entirely within various spectral classes of forest canopy components such as illuminated pine tree crowns, hardwood tree crowns, illuminated and shadowed understory, etc. The great overlap of signature distributions was caused by the fact that each spectral class of canopy component occurred within several feature areas.

A proportion-space classification technique which we developed and tested on the previously discussed (2 meters)^2 data appears to offer substantial improvement for the classification of fine resolution data [6]. The technique entailed a two-stage procedure that ultimately discriminates features on the basis of average proportions of classified component spectral classes that occur within feature areas. The first stage of the procedure utilized the large variance in the data to classify resolution elements into their respective component spectral class, regardless of feature area. Signatures for the conspicuous component spectral classes in each feature area were defined with the aid of large-scale color-infrared photographs and a zoom transfer scope. Subsequent analysis indicated little capability for reliably discriminating between similar types of component spectral classes from feature to

feature. Therefore, we combined such signatures and assessed discriminability for the resultant eight signatures representing different spectral classes of canopy components. Table 3 indicates relatively high classification performances for this set of signatures when used to classify a selected set of resolution elements in feature areas.

TABLE 3.--RESULTS OF CLASSIFYING SELECTED RESOLUTION ELEMENTS IN ALL FEATURE AREAS

Component Spectral Class		Percent Correct	
Illuminated Pine Crowns	Class I	72.9	90.8
	Class II	84.5	
Illuminated Hardwood Crowns	Class I	86.9	92.3
	Class II	70.0	
Illuminated Leafless Trees		95.3	
Shadowed Pine Crowns		87.1	
Shadowed Understory		96.2	
Illuminated Understory		90.4	

When the eight component signatures were used to classify representative regions of data within each feature, expected differences occurred in the proportions of resolution elements that were classified into the various component spectral classes. Figure 8 illustrates the

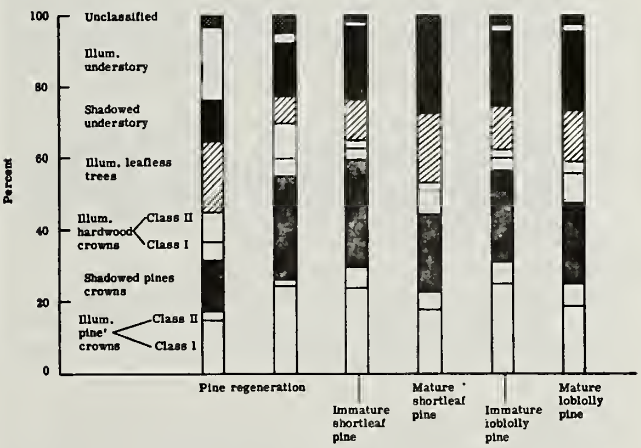


FIGURE 8.--PROPORTIONS OF CANOPY COMPONENT SPECTRAL CLASSES THAT OCCURRED WITHIN AREAS REPRESENTATIVE OF EACH FEATURE

differences in component proportions for the regions of data classified within each feature. (Note that two separate data regions were classified within pine regeneration in order to observe the extremes of tree density that existed within the feature.)

For the second stage of the procedure, we utilized the differences in component proportions within each feature to discriminate among features. Each representative data region was partitioned into cells of 1000 $(2m)^2$ resolution elements (each cell measuring 50M by 80M ground coverage). For each cell, we established a new data vector giving the proportions of previously classified component spectral classes. Thus, a new "proportion space" was defined for describing the cells. These data vectors were averaged together to compute signatures defining component proportions in each feature. Finally, the proportion signatures were used to classify each 1000-element cell in proportion space. Figure 9 illustrates the greatly improved performance achieved for the proportion-space technique as compared to the conventional classification performance previously achieved with fine resolution data.

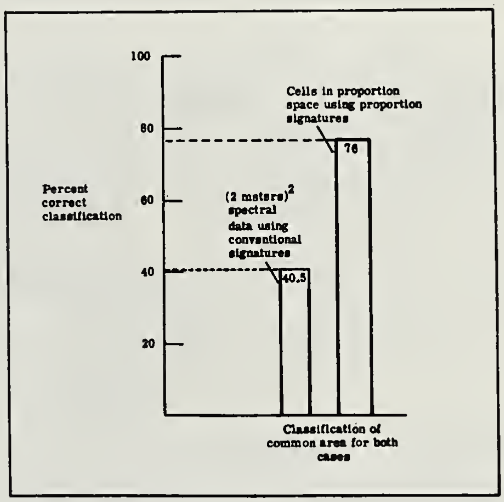


FIGURE 9.--COMPARISON OF PROPORTION-SPACE AND CONVENTIONAL CLASSIFICATION PERFORMANCE AVERAGED OVER ALL FOREST FEATURES

The procedure described here demonstrates the potential utility of fine resolution MSS data for forest resource surveys. The capability to classify such data into various spectral classes of forest canopy components can in itself provide information to support intensive forest management efforts. For example, proportions of classified canopy components enable the determination of crown closure for various tree crown spectral classes that may influence

management decisions affecting silvicultural or pest control operations. Additionally, the application of the proportion-space classification technique can provide accurate forest feature discrimination at a more general level. Such capabilities could be advantageous in multi-stage sampling surveys where finer resolution MSS data is acquired on a partial basis according to a sampling strategy and used to augment the complete coverage provided by coarse resolution data.

SUMMARY

Tables 4 and 5 summarize the results treated in the previous discussion of three factors that influence MSS data classification performance for forest resource inventories. For the application of a conventional processing technique, the effects of systematic variations in spatial resolution and level of desired detail are presented in Table 4. Table 5 presents the effects of using specialized processing techniques on coarse and fine resolution data. The implications for resource managers are stated in an effort to provide the basis for establishing guidelines regarding the use of MSS systems for natural resource inventories.

TABLE 4.--SUMMARY TABLE FOR SPATIAL RESOLUTION AND LEVEL OF DESIRED INFORMATION GIVEN THE APPLICATION OF A CONVENTIONAL PROCESSING TECHNIQUE TO MSS DATA

FACTOR	DEMONSTRATED INFLUENCE ON CLASSIFICATION PERFORMANCE	IMPLICATION FOR RESOURCE MANAGERS
Spatial Resolution	Coarser is more accurate	Let feature size and shape dictate coarsest case of spatial resolution
Level of Desired Information	General is more accurate	Avoid too specific features whose discriminating criteria are insensitive to analysis by conventional multispectral processing techniques

TABLE 5.--SUMMARY TABLE FOR SPECIALIZED PROCESSING TECHNIQUES APPLIED TO MSS DATA

FACTOR	DEMONSTRATED INFLUENCE ON CLASSIFICATION PERFORMANCE	IMPLICATION FOR RESOURCE MANAGERS
Multi-Element Classification	Offers improved performance in a manner analogous to the coarsening of spatial resolution	1. For a given resolution, can obtain the improved performance of coarser resolution without the loss of location and mensuration accuracy 2. May enable acceptable classification of more detailed features
Proportion-Space Classification	1. Good classification of fine resolution data into major components of forest canopies 2. Dramatically improved feature classification using proportions of canopy components as discriminating criteria	With two-stage processing, fine resolution data can provide information of a very detailed as well as more general nature

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Remote Sensing Streams[1]

Paul Cuplin[2]

Abstract.--To accelerate stream inventory and documentation of existing stream habitat conditions, stream remote sensing techniques were tested. Two aerial platforms were successfully used for continuous aerial stream photography. Color infrared and Ektachrome X film when properly exposed produce very good water penetration in clear streams. Stream habitat conditions such as stream shade, upper stream bank condition, stream bank stability, stream channel stability and percent stream bottom silt can be interpreted from large scale color infrared photography.

INTRODUCTION

Stream inventories must often be completed in a short period of time with a limited staff. To accelerate stream inventory and improve baseline resource data remote sensing techniques are needed. The present aerial photography available in field offices is not large enough scale to allow for interpretation of stream habitat conditions. Large scale photography with water penetration capability is needed for stream habitat evaluation.

Two aircraft platforms were tested for remote sensing streams. An aircraft door camera mount and an aircraft floor camera mount.

Kodak color infrared and Kodak Ektachrome X film were tested to determine applicability for stream inventory.

A Nikon 35mm motor drive camera with 50mm lens was used in all tests. The 35mm format required enlargement with a Vantage II microfilm reader for interpretation of stream conditions.

Stream habitat inventory was accomplished by first ground truthing the stream for stream shade, upper stream bank condition, stream bank stability, stream channel stability and percent stream bottom silt. Linear distance between prominent land marks was measured to establish photographic scale.

Methods

A Nikon F2 35mm motor drive camera with 50mm lens with Wratten 12 filter and Kodak Ektachrome color infrared film was used to photograph portions of Red and Rio Grand Rivers in New Mexico on October 30, 1975. The camera was mounted on a door mount platform, described by Meyer 1973, on a Cessna 182 aircraft. The camera light meter with filter in place was read and set at 1/2 f stop overexposure. The aircraft was operated at 100 mph and at 2000 feet above datum due to the 800 foot canyon in the lower portion of Red River.

The Nikon F2 camera was again used with Wratten 3 filter and Ektachrome X ASA64 film to photograph the same portions of Red and Rio Grande Rivers on May 5, 1977. The camera was mounted in a Cessna 182 aircraft equipped with a camera floor mount designed by W. E. Woodcock, Miles City, Montana. The camera light meter was read with Wratten 3 filter in place and adjusted for a 2 f stop overexposure to achieve water penetration with Ektachrome X film as described by Lockwood, et al, 1974.

A camera shutter speed of 500 was used with both color infrared and Ektachrome X film. The camera lens was set on infinity and taped in place with masking tape to prevent lens movement during flight.

The 35mm format used in all tests required enlargement with a Vantage II microfilm reader

[1]Paper presented at the Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.
[2]The author is a Fisheries Biologist employed by the Bureau of Land Management, Denver Service Center, Denver, Colorado.

with F series lens for interpretation of stream habitat conditions.

A stream habitat inventory was accomplished by first ground truthing the area to be photographed and measuring the linear distance between two prominent land marks. Stream shade, upper stream bank condition, stream bank stability, stream channel stability and percent stream bottom silt were rated and the ratings for each category summed for an overall numerical and adjective stream habitat rating.

Aerial flights were not made if cloud cover exceeded 15 percent. Flights were scheduled from 11 a.m. to 1 p.m. for maximum sun azimuth to reduce shadow as much as possible. The maximum sun azimuth and "peak of green" for vegetation occurs between June 1 and August 30 in the temperate zone of the United States. It was not possible for aerial photography to be completed during this period of time. Therefore, dates as close as possible to this period in May and October were selected.

Results

Kodak color infrared film overexposed 1/2 f stop provides water penetration in clear streams. Figure 1.

Ektachrome X film with a Wratten 3 filter and 2 f stop overexposure gives good water penetration in large streams, Rio Grand River, and medium size streams, Red River. Figure 2.

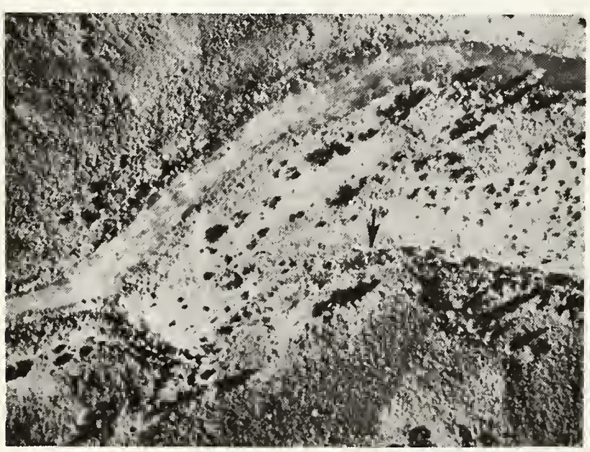

Figure 1.--Red and Rio Grande River, Oct. 30, 1975, photographed at 2000 ft. with Nikon F2 50mm lens Wratten 12 filter with 1/2 f stop overexposure. Clear water is penetrated in smaller stream Red River (arrow) but not the larger Rio Grande River. (Magnification required to see stream details.)

Figure 2.--Red and Rio Grande River May 5, 1977 photographed at 2000 feet with Nikon F2 50mm lens Wratten 3 filter with 2 f stop overexposure. Stream bottom of both streams can be clearly observed.

The aircraft door camera mount and the aircraft floor camera mount were both satisfactory for continuous strip photography of streams.

35mm format enlarged with a Vantage II microfilm reader can be used for photo interpretation of stream habitat.

Discussion

The aircraft floor camera mount provides greater operator safety and accuracy of camera operation than the aircraft door camera mount. The photographer can view the target through the camera range finder inside the aircraft whereas the door mount system utilizes a sighting device for judging target location.

The 35mm format provides economy for experimental use but has the disadvantage of small size and potentially large number of individual slides that must be identified and handled.

Larger formats 70mm, 5x5 or 9x9 can be more easily handled with a light table and stereo magnification.

The color infrared film gave good water penetration in clear streams with 1/2 f stop overexposure. Riparian vegetation shows up well at this level of exposure.

Ektachrome X with Wratton 3 filter and 2 f stop overexposure provides good water penetration and evaluation of stream bed sedimentation. Riparian vegetation is not easily identified in the yellow and brown colors that result from

this exposure. This method does not provide the contrast in colors found in CIR film which allows for evaluation of stream habitat conditions.

Acknowledgements

Thanks are extended to Richard Kerr, Wildlife Staff Leader, Denver Service Center, Bureau of Land Management who encouraged the development of remote sensing techniques for streams, to Fred Batson, Montana State Office, BLM for providing equipment and expertise in techniques used in remote sensing, to Wally Crisco, Office of Special Mapping, BLM, Denver, for his help in photo interpretation and analysis.

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Panel VI — Principles for Integrating Inventories of Renewable Resources: Moderator's Comments[1]

Kenneth D. Ware[2]

Abstract.--Several principles are paramount for designing systems to inventory renewable resources on a recurring basis. Adequate design requires specification of (a) objective (analytic vs. enumerative, managerial vs. descriptive, etc.), (b) alternative schemes for selection and estimation, (c) cost-effectiveness criteria, (d) techniques of field observation, (e) common units of measure, and (f) procedures for estimating interaction relationships among resources.

INTRODUCTION

The principles for integrating inventories of renewable resources are extensions of the principles for designing inventories of a single resource on a one-time basis. In both instances the purpose is to discover useful information to guide management. Designing integrated inventories is more complex because information must be gathered on many resources and it must be useful over a long timespan. This challenging problem provides great opportunities for the inventory designer to improve cost effectiveness in information gathering.

It will be useful to review some dominant principles for designing any resources inventory. These principles are by no means universally recognized, understood, or applied. For those interested in some modest extensions of orthodox sampling concepts in the directions of management science and the needs for information by resources managers, we shall in this, and some of the succeeding papers on this panel, reiterate and illustrate these principles.

Then we shall attempt to sketch the problem of integrating multiresource inventories so as to indicate how some of these principles might be applied. In much of this you will find nothing very new or startling; you will find no ready recipe, no cure-all general purpose design. Almost all of this panel's message has been said or implied elsewhere in the literature and classrooms. It nevertheless seems desirable to till that ground once again, considering the light harvest from past tillage. After I attempt to lay out the field and allocate the acreage to the crops, I shall leave it to this well-qualified panel of plowmen. In some cases you will notice that we are plowing, cross-plowing and harrowing.

SPECIFYING INVENTORY OBJECTIVES

How can one decide the best way to get there until one has decided where one wants to go; decide upon <u>means</u> before specifying <u>ends</u>; or choose rationally among alternative strategies without a stated objecitve? Obviously, there is no way to do so. Those who have worked to specify rational objectives for resources inventory know how difficult this specification can be, even for the one-time estimation of a univariate mean.

Several speakers on this panel will address this important and challenging aspect of the design problem. Hamilton mentions the shortcomings of our most-often-used approaches to specifying inventory objectives, and sketches how more rational approaches based on decision theory may be useful in designing inventories to provide information for management decision. To make his exposition clearer, he has confined his examples to single variates and simple well-specified decisions.

Frayer treats the difficulty of specifying objectives for a multiresource inventory. He emphasizes the need for explicitly recognizing analytic objectives (involving interactions among resources) as well as the objective of

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[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.

[2]Chief Mensurationist and Research Leader, Institute for Forest Ecosystem Decisions, U. S. Forest Service, Southeastern Forest Experiment Station and University of Georgia School of Forest Resources cooperating, Athens, Georgia.

estimating current stock. He also reminds us that managing multiple renewable resources requires inventory information about resource trends and future responses to present practices. Ware and Hughes (1973) covered some aspects of such requirements under the heading of "management response trajectory." Frayer also calls our attention to the implications for inventorying on successive occasions.

Stuck and Burkhart give an example applying these ideas for designing inventories to provide information for certain land-management planning decisions.

These papers dealing with objectives should convince us that we not only must -- but can -- abandon the "10% cruise" where we routinely first specify the means and let the ends tag along. We all know now, do we not, that rational specification of sampling fraction or sample size is one (but only one) of the major means that the inventory designer has for satisfying design objectives to provide the information needed to satisfy the manager's ends?

Our first principle for design, then, is that a rational, logical, and comprehensive statement of inventory objective is required. This statement must link the inventory objective (such as a precision requirement) to the decisions that are to be made from the multi-resource information provided by the inventory.

SPECIFYING ALTERNATIVE INVENTORY DESIGNS

When we have adequately specified the inventory objective, working back from the resource manager's decision problem, then we must consider the alternatives available to us for satisfying this objective. What sampling designs will provide the information? What will be the properties of the estimates? What will be the cost?

We have a vast and increasing array of feasible alternatives in each major phase of the design (combination of selection rule and estimator). We have choices of definition of variables and units of measure, specification of population, sampling unit and frame, selection rule and technique, estimator, and sampling property to be the basis of inference. And, of course, these are all interdependent and must be considered together when we are specifying the set of whole "composite" designs.

Too often we do not consider a reasonable array of alternatives and do not even carefully specify the few we consider. Commonly the latest fad is compared only with simple random or systematic sampling or with whatever is being presently applied. This topic has, however, been discussed elsewhere and there is not space here to reiterate (Ware and Hughes 1973; Ware 1974, 1975).

Scattered throughout these proceedings will be information about alternatives in the various aspects of design. But in this panel we have the task of providing principles for integrating all information about alternatives into one cost-effective design for a given set of circumstances.[3] In addition to the general treatment in several papers, the papers by Beers, Chapman, Ek, and Wiant each deal with some specific aspects and alternatives.

Ek proposes that, as an alternative to our traditional uses of prior information, we exploit it in a certain explicit probability sense. To determine whether this Bayesian way of using prior information will be more or less effective than traditional alternatives (stratification, control of selection probability, etc.), will require a thorough analysis of a comprehensive list of alternatives to evaluate cost-effectiveness. However, suppose we have information that analysis shows to be beyond what might already have proven useful for and be exploited for stratification, indirect estimation or control of arbitrary selection probabilities. Then we may consider adding to each of our other traditional alternatives an additional phase involving a Bayesian approach based on the prior distribution.

Our second guiding principle is that, through our knowledge of the population to be sampled and of design alternatives, we exploit sampling principles (stratification, clustering, randomization, selection with arbitrary probability, indirect estimation, Bayesian priors, etc.) to specify a comprehensive set of alternative inventory designs.

DECISION CRITERIA FOR CHOOSING AMONG DESIGNS

If we have been successful in adequately specifying the inventory objective, and the feasible design alternatives, then we will require a criterion for choosing the "best" feasible design. When specifying the objective

[3] We panelists may not be quite adequate for the monumental task of integrating all that appears in these proceedings or even in our own panel. We may in some respects be an exhibit for the poor state-of-the-arts in applying rational principles for specifying alternative inventory designs. In our own defense we may only claim that we did not understand our assignment to be mainly to illustrate the principles we espouse.

we sometimes combine the decision criterion into the objective. A simple textbook example; we may say that we want to estimate some population total with specified precision at minimum cost. That is, we want to choose, from the designs feasible for achieving the specified precision, the design that will cause us to incur the least cost. Our decision criterion is then <u>minimum cost</u>.

It is clear that as the number of managerial objectives and the complexity and interactions among variables increase, the decision criterion must also be more comprehensive. Frayer, Hamilton, and Stuck and Burkhart all discuss various decision criteria. Hamilton, and Stuck and Burkhart use a "minimum cost-plus-loss" criterion in linking the inventory design problem directly to the resource manager's decision problem. When we can do this we alleviate the common difficulty of rationally specifying precision or budget for an inventory.

So our third principle is that the criterion for choosing among the feasible alternative designs should be the one most relevant to the decision environment (cost, risks, etc.) in which the inventory information will be used.

FIELD OBSERVATION AND UNITS OF MEASURE

What about observational techniques and units of measure? These have occupied a great deal of our attention in single resource inventories. We have devoted most of our forest mensuration to measurement techniques (and those for timber outputs only). The same emphasis on such techniques holds for range, water, and wildlife resources.

However, even when considering only one resource (e.g., timber), we have not been very careful to integrate our knowledge of the underlying subject-matter concepts and relationships with our knowledge of the concepts and principles of sampling and estimation. For example, even where we have been interested in estimating fiber yields, we are only now beginning to exploit the obvious geometric relationships between tree dimensions, volumes and weights, and fiber yields.

If we think about it, we realize that our definitions of variables, our measurement or observation techniques, and our units of measure must be integrated with the inventory objectives and the specified design alternatives (selection rules, estimators, etc.). But usually we do not work it through; instead, we do what has become routine from past practice. Certain index variables, which permit only indirect estimates of the variables of interest, become sacred cows -- ends in themselves. Basal area (of trees in a stand) may be one such variable. Certain field observation or indirect estimation procedures crystallize and we forget why we first developed and applied them. For example, we take volume tables, site-index curves, etc., for granted with not much attention given to whether there might be a better way.

Although we have years of experience, multitudinous data, and numerous publications about the idea, many of us are just now discovering the "volume/basal-area line" and different "volume/basal-area lines" by height classes. The elementary theory for geometric solids, (which once was reviewed in forest mensuration texts) gives us this directly. Furthermore, it seems reasonable to presume that anyone who understands the principles of sampling with arbitrary probability has deduced how to integrate the principles of measurement and sampling for that application to timber volume and weight estimation. In one of his earliest papers on point sampling, Grosenbaugh (1952) suggested that users apply these principles so as to make it necessary only to tally trees by height classes and use the ratio of volume to basal area (the volume/basal-area line, volume line, tarif line, or whatever name you prefer). Extensions to weight are self-evident.

However, because of our profession's emphasis on procedures rather than principles, many still struggle to get "the recipe". To attempt to get the point clear, let us look more closely at weight estimation of standing trees as an illustration of how the principles relate to observational techniques, etc.

We begin with the knowledge from long experience that the boles of trees are shaped approximately like one of the geometric solids of circular cross-section. The volumes of these are simple functions of their dimensions, viz., diameter, whence cross-sectional area, a, and height, h. This relationship is of the form

$$V = \text{volume} = k(a)(h)$$

where

a = cross-sectional area at base
h = height from base to tip
k = a constant, different for each geometric form.

Several generations of foresters have known[4]

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[4] "Trees of the same d.b.h. and height will still vary in cubic volume. This is due to variation in the taper or form of the boles. The range of variation in form is from that nearly approaching a paraboloid to that which approaches a cone." (Chapman and Demeritt 1932, p. 59.)

that for most whole coniferous trees, $1/3 \leq k \leq 1/2$, as can be verified from any volume table based on D^2H as the independent variable.

To put this another way, volume is approximately proportional to basal area for trees of given height, with a different constant of proportionality, k, (or ratio of volume to basal area) for each height class. Or we may look upon this relationship as a family of lines with a different slope for each height class and take the ordinate value (volume) for these at a specified value of the abscissa (basal area) as an index number or "tarif" by which to characterize the lines.

Now to consider the sampling aspects. From the theory of sampling with arbitrary probability we have the Horvitz-Thompson estimator

$$\hat{Y}_t = \sum_{i=1}^{n} \beta_i y_i$$

where

$\hat{Y}_t$ = estimator for $Y_t = \sum^{N} Y_i$, the population total of the variate of interest

y_i = observation of variate of interest on i-th element

β_i = constant to be used as a weight for i-th element whenever it is selected for the sample of n.

The only unbiased estimator is

$$\hat{Y}_t = \sum_{i=1}^{n} y_i/P(u_i)$$

where

$P(u_i)$ = probability that the i-th unit, u_i, is selected in the sample of n from population of N.

(Note that β_i is a constant, so if $P(u_i)$ depends on the sample size, n, then n must be a fixed constant.) If we can arrange an appropriate selection rule to make

$$P(u_i) = n(y_i/Y_t)$$

then we have

$$\hat{Y}_t = \sum_{i=1}^{n} y_i/[(ny_i)/Y_t] = Y_t \sum_{i=1}^{n} (1/n)$$

$$= Y_t(1/n)(n) = Y_t.$$

This means we have an unbiased estimator with variance zero; $\hat{Y}_t = Y_t$, our estimate equals the parameter, for every sample, regardless which units were selected for the sample. To put it another way, if we can find a way to select with probability exactly proportional to the variable of interest (which, as can be seen, requires a fixed sample size) then we have the best of it all. This is so because, if

$$P(u_i) = c(y_i)$$

then for any value of the constant of proportionality, c, so long as we know it independently of the sampling, we can construct the unbiased estimator with no variance. It is usually impossible, of course, to arrange a selection rule to give a fixed sample size with selection probabilities exactly proportional to the variable of interest, y_i.[5] Nevertheless, we often can select with probability proportional to some concomitant variable or "measure of size", x_i, so that, say,

$$P(u_i) = c'x_i.$$

But if y_i were exactly proportional to our concomitant, x_i, <u>i.e.</u>, if

$$y_i = c''x_i$$

then

$$P(u_i) = c'(1/c'')(y_i)$$

and the selection probability is still proportional to y_i. Consequently, we strive for a way to select with probability exactly proportional to a concomitant, x_i, which is in turn as close as possible to being proportional to y_i. The variance of the estimator then depends only on the variability in the relationship of y_i to x_i (or any other sources of between-samples variation in c'/c'', such as sample size, n, not being constant).

How does this integrate with our knowledge of point sampling as an illustration of how the principles may be exploited to put together selection technique, estimator, definition of variable, field observation, etc.? The horizontal point sampling technique leads to probabilities of selection proportional to tree basal area, a_i, so that for one point drawn at random, the probability that the i-th tree, u_i, will be selected in the sample of n trees is

$$P(u_i) = ka_i.$$

Since $P(u_i) = mka_i$ for m random draws or points, for the estimator we have

[5] If we knew y_i for all N units in the population we wouldn't need to sample!

$$\hat{Y}_t = \sum_{i=1}^{n} y_i/P(u_i) = \sum_{i=1}^{n} y_i/mka_i$$

$$= (1/mk)\sum_{i=1}^{n} y_i/a_i.$$

Now if the variable of interest, y_i, is basal area, i.e., $y_i = a_i$, then

$\hat{Y}_t$ = estimate of total basal area for all N trees

$$= (1/m)(1/k)\sum_{i=1}^{n} a_i/a_i = (1/m)(1/k)(n)$$

$$= (1/k)(n/m).$$

We recognize 1/k as the product of the "basal-area factor" on a per-unit-area basis, and the total area in the population. And since n is the number of trees taken into the sample and m is the number of sample points, the quotient n/m is the average count of trees selected per point. Now k and m are constants, and if we had a selection rule which made the sample size, n, a constant rather than a sample variable, then we would have for basal area the unbiased estimator with variance = 0. Here we do not have variance = 0, because although we do have the single-draw probability of selection of each unit exactly proportional to the variable of interest, the exact proportionality does not hold for the total probability of inclusion in the sample of n (since n is not fixed), based on m draws.

If now the variable of interest is volume, i.e., y_i = volume, v_i, then our estimator of the total,

$$\hat{Y}_t = \sum_{i=1}^{n} y_i/P(u_i),$$

since $P(u_i) = mka_i$ for m points, becomes

$$\hat{Y}_{t,v} = \sum_{i=1}^{n} v_i/mka_i.$$

We know, however, that volume is approximately proportional to basal area. Let us assume for the moment it is exactly proportional so that

$$v_i = ra_i$$

with r being the constant of proportionality (or volume/basal-area ratio). So substituting, and factoring constants from the sum, we have

$$\hat{Y}_{t,v} = \sum_{i=1}^{n} ra_i/mka_i = (1/k)(r)(1/m)\sum_{i=1}^{n} \quad (1)$$

$$= (1/k)(r)(n/m)$$

= (Basal-area factor)(volume/basal-area ratio)(average tree count per point).

There is, of course, nothing new here. The basal-area factor is a constant and we have assumed that the volume bears a constant ratio to basal area. We know from experience, however, that while this is nearly so for trees of a given height, it is variable from one height class to another due to differences in form, the relationship of height to diameter. This is the old stuff of the volume/basal-area line, tarif lines, and is the basis of Grosenbaugh's (1952) original advice to post-stratify the sample by height classes with a different r for each.

Furthermore, since weight is proportional to volume (as it must be except for variation in specific gravity), volume is proportional to basal area, and our selection is with probability proportional to basal area, then whatever works well for basal area and volume will work well for weight estimation. And so will it work for any variable proportional to basal area. To have an estimator with nice properties we simply count the number of trees selected with the angle-gauge and multiply this by appropriate constants of proportionality. (This is what Beers calls "obviation" and the constants of proportionality, etc., are called "factors".) If the constants are not known before sampling (or are variables rather than constants), then we may wish to estimate them in the second phase of a double sample so as to retain some of the potential gains from selection with probability proportional to a measure of size (p.p.s.).

Also we can readily generalize to other bases of stratification and relationships of volume and weight to basal area, and to other useful concomitant variables of the tree or stand, by using any function of the concomitants that preserves the proportionality with basal area. We can have

$$v_i = [r'a_i][g(x_j)] = [(r')g(x_j)]a_i$$

where $g(x_j)$ is any function of tree or stand concomitant variables, x_j (such as average height, or any other measure of height/diameter relationship in a stand), which preserves "adequate fit" of the volume/basal-area lines so that the ratio r' is thereby "adjusted" to fit the j-th class more precisely.

Therefore, to summarize, if we understand a) the relationship of the variable of interest to observable concomitants, b) the fundamental concepts of sampling with arbitrary probability, and c) how we can devise (if we do not already

have at hand) an appropriate technique for selection and field observation to give us an arbitrary probability sample based on these concomitants, then we can readily specify an efficient sampling design that integrates these principles. Since weight is proportional to volume and volume proportional to basal area, we can exploit horizontal point sampling, not only to have an efficient scheme for selecting units, but if the constants of proportionality are known we can obtain our estimates by simply counting the selected trees and multiplying by the constants. Otherwise, of course, we have to observe the weights or volumes directly or estimate them indirectly via double sampling or some other approach. We can operate analogously for any other scheme for selecting with arbitrary probability -- not just for horizontal point sampling.

This, as you will see, is the basis for the techniques Beers will describe. He provides details and examples of how these principles are integrated and exploited in "poly-areal plot" sampling.

A fourth principle then is that, in defining concomitant variables and specifying units of measure and techniques for field observation, we should explicitly exploit knowledge of subject-matter relationships, of logistical and practical aspects of the field context, and of the sampling design alternatives to integrate the final design.

MEANS FOR ESTIMATING INTERACTION RELATIONSHIPS

Designing a resources inventory that is cost effective for estimating management response trajectory or relationships (analytic objective) is difficult. We have little in theory or experience -- only basic principles -- to guide us.

We want to design an integrated inventory for several resources that provides the kind of information managers need to estimate management responses and choose among alternative strategies. This requires the estimation of multiple interacting management response trajectories -- what we often call "interaction relationships". Frayer and Stuck and Burkhart mention this topic in their papers. Alvis implies a great deal about it in his paper. Hazard (1974) and others have attempted some formal analyses of sample design for optima with multiple variables that are interacting. They have, however, emphasized estimation of current levels or changes over a period for each variable rather than the estimation of response relationships.

It is evident that formal research is badly needed to integrate traditional sampling design concepts with management science and methods for estimating relationships from nonexperimental data (Ware 1975). Otherwise we are reduced to taking the most defensive and unscientific posture -- taking a broad self-weighting sample and observing almost everything we can think of without trying to optimally allocate our effort -- so that we can't be "too far wrong". We seem to be assuming that any one simple random-like sample is better than any design alternative. Although one might rationalize this way for a "super-population" of objectives and applications over the long run, this does not seem very good for the short run world in which we work.

SUMMARY

In designing integrated multiple-resource inventory systems we strive to be more effective by applying several principles:

1) A rational and comprehensive statement of inventory objective should be specified to link syllogistically with the decisions that are to be made from the information provided by inventory.

2) Through knowledge of the population to be sampled and of design alternatives that will effectively exploit sampling principles (randomization, stratification, selection with arbitrary probability, indirect estimation, etc.) we should specify a comprehensive set of alternative inventory designs feasible for the objective.

3) The decision criterion for choosing among alternative designs should be the one indicated to be most relevant by analysis of the decision environment (costs, risks) in which the inventory information will be used.

4) In defining concomitant variables, specifying units of measure and deriving techniques for field observation we should exploit knowledge of the subject matter relationships (biological, physical, economic, etc.) among variables, of the logistical and practical aspects of field environment where sample selection and observation take place, and of the relevance of this to sampling design alternatives.

5) To enhance the value of the results of inventory for analysis and prediction, we should incorporate whatever is currently known about efficient ways to sample for analytic objectives and for estimating interaction relationships from nonexperimental data.

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Objectives of Multi-Resource Inventories in Relation to Design Considerations[1]

W. E. Frayer[2]

Abstract.--Resource inventories must be tailored to end objectives; conduct of an inventory satisfies only a set of intermediate objectives. The types of decisions to be made and kinds of information needed as input to decision making must be specified prior to design of an inventory. Intermediate objectives to be satisfied by the inventory process must be cast in terms leading directly to design criteria.

INTRODUCTION

Decisions are usually based on a mix of information. Some of the newer decision making aids including certain types of mathematical programming are suited for problems involving several variables and their joint outcomes. However, even when involved with only one basic output -- such as wood -- the decision maker is generally faced with questions regarding various product mixes (alternative outcomes). When other outputs such as water and wildlife are involved, the decision making task is more complex but not necessarily different in concept.

The same may be said of the inventory process. Multi-resource inventories are relatively new in terms of widespread interest. However, most existing inventories are multivariate -- at least in terms of application. Even when dealing with one output, many items of information are sought.

FALLACY OF THE UNIVARIATE CONCEPT

For years sampling practitioners have been schooled in the theory and application of univariate sampling. The reasons are many and, for the most part, justified. We should admit, though, that such methods are somewhat divorced from reality. Consider, for example, a timber inventory of a single industrial holding. What are the reasons for conducting the inventory? Presumably, management decisions are needed. Occasionally a single decision involving a single variable may be at stake. More commonly, decisions are needed which require information on the current state of the timber resource. A single variable such as total wood volume only provides part of the information. Stand structure, growth, harvesting alternatives and associated profits are also needed. A common solution has been to design and carry out an inventory with intensity based on allowable sampling error for one item of interest -- a traditional univariate sampling approach.

With luck, reasonable precision levels may be achieved for all items eventually used by the decision makers. All is not safe (or lost) however. There is a real chance that a univariate sampling expert will soon appear on the scene with his bag of tricks. He can usually point out -- quite convincingly -- that cost savings are possible through optimized design. Simple modifications such as stratified sampling with optimum allocation may be suggested. Indeed, the estimate of the design variable may be achieved at a substantial reduction of cost. However, what happens to the other estimates plugged into decision models? There is a real danger that these may be sacrificed, leading to faulty decisions and eventually resulting in mutual mistrust.

Let us consider another example -- the U.S. Forest Service's Forest Survey which is now known as Forest Resources Evaluation Research. For many years, Forest Survey has conducted nationwide timber inventories. A new charge has expanded this task to include other renewable resources. This is certainly an impressive charge and one that has obvious implications on sampling design. Before looking at this expansion to multi-resources, though, let

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[1]Paper presented at the Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 9-12, 1978.

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me describe how Forest Survey has operated in the past.

Paramount among the information provided by Forest Survey is the input to decisions of the U. S. Congress regarding management of public lands and assistance to private landowners (Fig. 1). What kinds of questions must be faced by the Congress? Simply put, they need information on "how much we have," "how much we need," and how to achieve a balance. Forest Survey then should be providing--as they have done and continue to do--reliable information on resource quantities, demands, and potentials. Sampling design implications include efficient estimation of current quantities, demands, and historical trends. Successive sampling for predictive or forecast purposes is implied for many variables in addition to timber volumes. Population trends, consumer preferences, labor costs, income and many other variables are a part of the information needed.

Whether we like it or not, we have been involved with multivariate inventories for a long time. And, while progress in refining univariate sampling methods has been rapid, we have been progressing at a slow rate in recognizing, accepting, and applying concepts and methods of multivariate sampling.

OBSERVATIONS ON MULTI-RESOURCE INVENTORIES

Conclusions regarding objectives of multiresource inventories in relation to design considerations are difficult to make. Some observations, though, are in order.

The objective of an inventory is to supply information needed for decisions (Fig. 2). The types of decisions to be made are the driving force for the inventory system. These must be specified in advance, the information needed should be couched in terms translatable to data needs, and the sampling design should be addressed to meeting the data needs. In order for this to function with any degree of success, all parties involved must communicate openly and intelligibly.

A second observation is related to sampling unit configuration. It is unlikely that a single type of sampling unit will suffice for measurement of several variables. For example, it was realized some time ago that fixed-radius plots of different sizes for trees of different sizes had advantages over plots of a single size. More recently, in the application of point sampling, different basal area factors have been used for species of different values. As I have tried to point

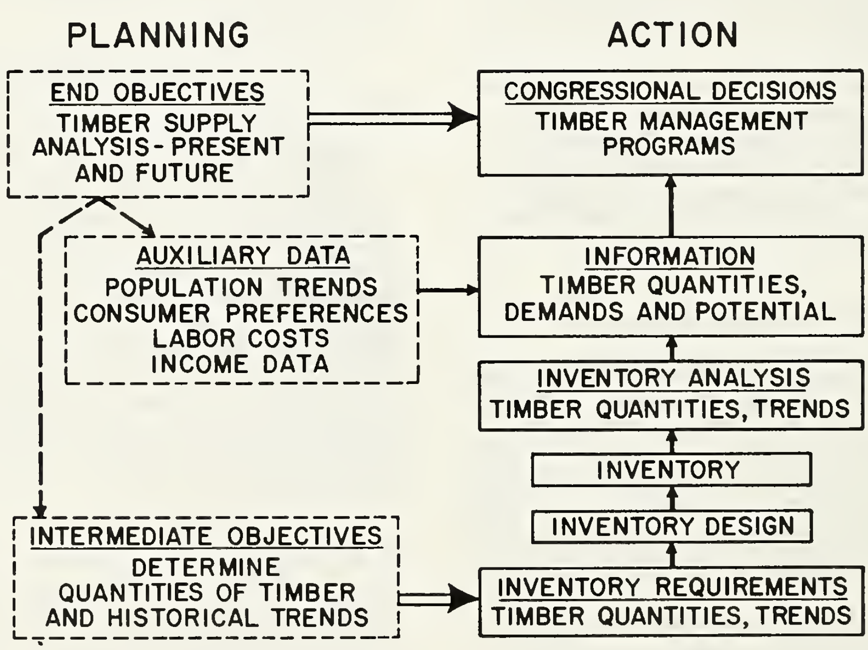

Figure 1.--Schematic of a decision-making system involving Forest Survey timber inventories.

out in this paper, the inclusion of many resources in an inventory is more complex but not dissimilar to a timber inventory with several variables of interest -- both are multivariate in nature.

Resource inventories generally involve large areas of land and the proportion of land sampled is generally quite small; that is, finite population corrections can usually be ignored. Consequently, sampling "points" can be selected, measurements made and converted to a per-unit-area basis, and the results compiled and analyzed with the finite population correction ignored. What is actually measured at the sampling points will depend on the variable(s) of interest. If timber volume is of interest, a selected basal area factor or fixed-radius plot may be used at the point. If operability is to be considered, a much larger area surrounding the point may be necessary for these factors. Similarly, if wildlife habitat parameters are to be estimated, a large, irregularly shaped unit of land area may be an additional sampling unit configuration used at the point. The data associated with a point would constitute observations on a single sampling unit.

Thirdly, decisions involving multiple resources usually involve interactions and payoffs between alternate and joint uses. This argues strongly in favor of measurement of all variables at identical locations for efficient estimation of interactions.

Next, trend levels are important because most decisions involving renewable resources are based on future (predicted) payoffs. This argues strongly in favor of a remeasurement scheme involving matched sampling units for efficient estimation of trends.

Summing up these observations, I believe that an efficient sampling design constructed for a multi-resource inventory may have the following characteristics:

(1) a sampling unit on which measurements are taken on areas of various shapes and sizes as needed, but related to a point,

(2) estimation of resource parameters with emphasis on interactions, and

(3) opportunity for remeasurement of sampling units at future occasions.

My last observation -- and conclusion as well -- is that most resource inventories are multivariate. Just as simple linear regression is widely accepted by most practitioners to be a special case of multiple linear regression (and multiple linear regression is accepted as a special case of a larger set of least-squares techniques), it is my hope that someday we will have advanced to a point such that univariate sampling methods are considered only a special case of a general, well-accepted, and realistic body of knowledge on multivariate sampling.

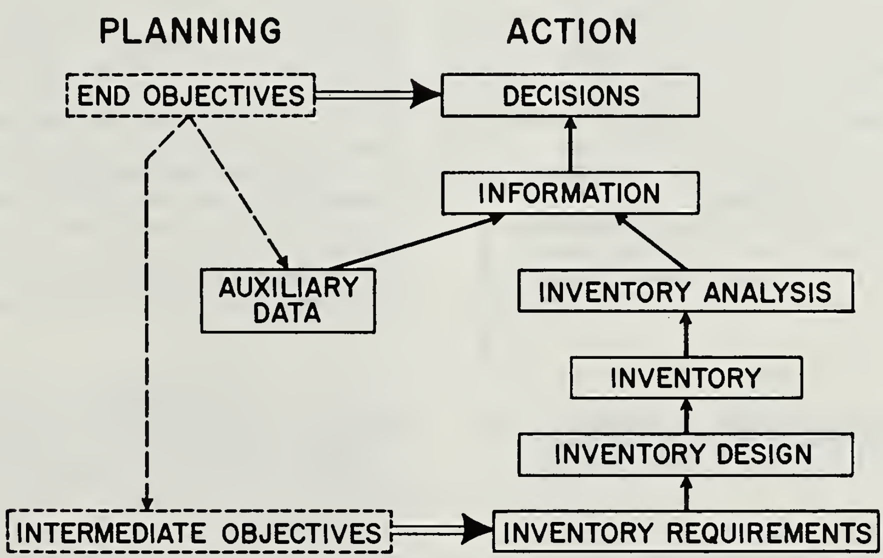

Figure 2.--Schematic of a decision-making system involving resource inventories.

Developing Efficient Estimation Techniques for Integrated Inventories[1]

Thomas W. Beers[2]

Abstract.--In the formulation of the general directions for a multi-purpose inventory, the designer must consider numerous estimation procedures. Variable probability selection, such as in point or line sampling, frequently provides very simple and efficient field and analysis methods. The general procedure for developing the necessary estimation formulas is discussed in this paper and several examples are presented. The challenge for the inventory designer is to assemble the appropriate set of techniques into one integrated field procedure.

INTRODUCTION

An integrated natural resource inventory, in most cases, involves some type of sampling. Although simple random sampling is frequently appropriate, the advantages of adopting a more sophisticated design should not be overlooked. Much has been written to guide the designer to developing his final plan. This paper will not be addressed to this phase of the problem. Instead, I will discuss inventory techniques at the level where we determine the type of fixed- or variable-size plots (i.e., equal or unequal probability sampling), and the appropriate estimation formulas to use. My primary purpose is to show that the "factor concept" gives one the tools to think expansively and to develop his own efficient inventory technique in a routine manner. The discussion will be restricted to vegetation inventories, although some of the concepts may be appropriate for other natural resources.

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[2] The author is Professor of Forestry, Purdue University, West Lafayette, IN. Paper approved by the Director, Purdue Agriculture Experiment Station as Journal Paper Number 6945.

STATISTICAL EFFICIENCY

The decision to use fixed- or variable-size plots in timber inventories is frequently made on practical grounds. Variable-size plots are often chosen because fewer stems need to be measured to provide precision equal to that obtained with fixed-size plots. The reason for this is basically statistical, since the most efficient sampling technique for the variable of interest, Y, is the one which selects sample trees with probability proportional to Y or proportional to another variable highly correlated with Y. This is the reason why horizontal point sampling (i.e., probability proportional to tree basal area) is so efficient for estimating stand basal area and stand volume (tree basal area and tree volume are highly correlated). Furthermore, fixed-size plot sampling is the most efficient statistically for estimating number of trees per acre. The inventory planner must be aware of the innate expected sample distributions of fixed- and variable-size plot sampling.

Several sampling situations are shown in Figure 1. In Figure 1(a) and Figure 1(b) fixed-size plot sampling and horizontal point sampling are efficiently matched with the parameters of interest, number of trees and basal area, respectively. However, in Figure 1(c) fixed-size plot sampling is somewhat inefficient for estimating basal area since the sample distribution of number of trees is considerably different from the population distribution of basal area. In Figure 1(d) which approach would more efficiently estimate

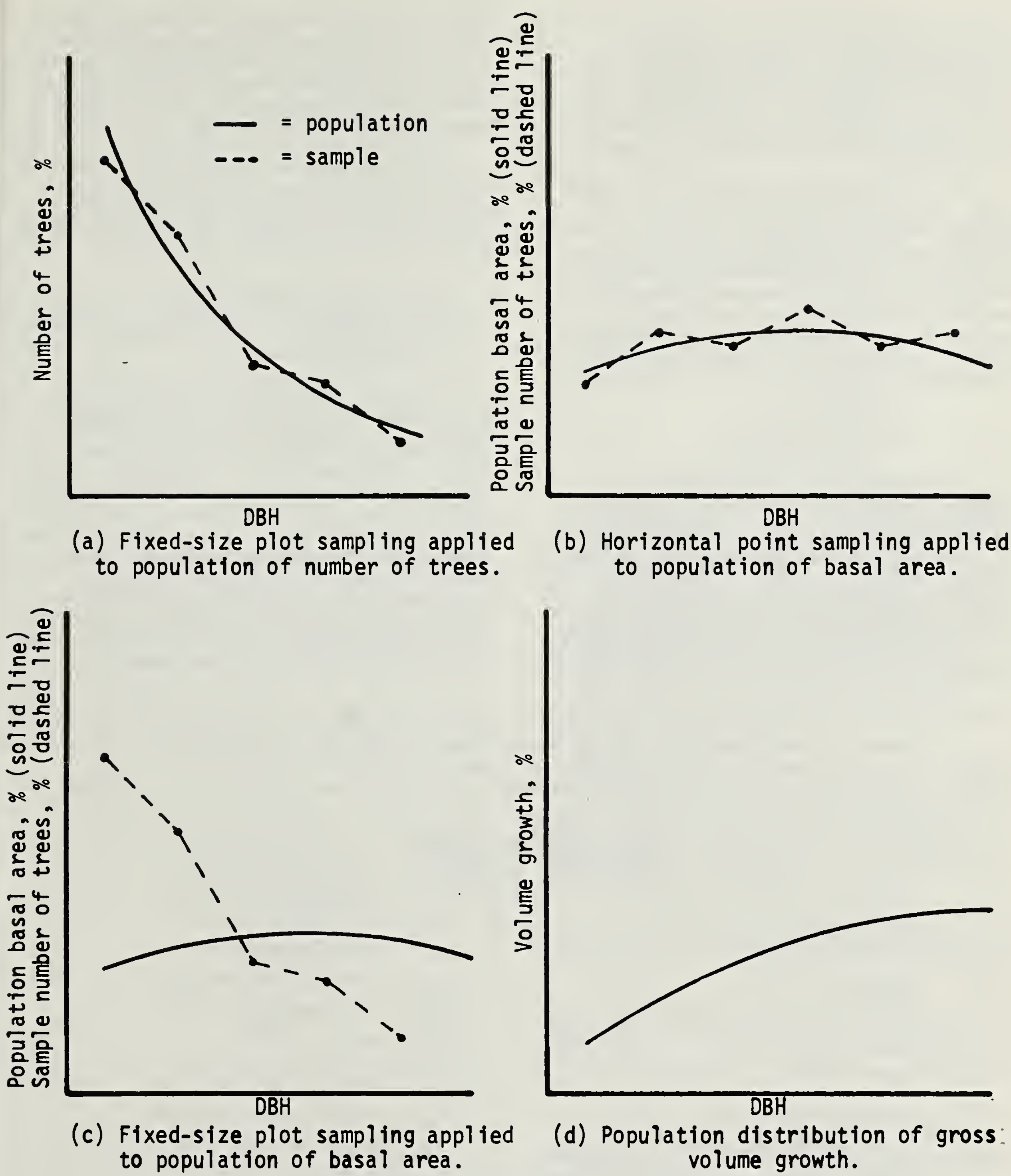

Figure 1. The relation of sample and population distributions for several sampling designs and stand attributes.

volume growth? Probably horizontal point sampling, but there are other types of variable probability sampling which may be better: horizontal line, vertical line and vertical point sampling. Inventory planning requires at least an understanding of the basic concepts of these systems of inventory.

The inventory planner must also be aware of the utility and advantages of non-areal types of variable probability sampling: list sampling and 3P (probability proportional to prediction) sampling. In these, statistical efficiency is further enhanced because the variance of the ratios of the variable of interest to the selection variable (estimate of size or value) is often much smaller than the variance of the raw variable of interest.

THE FACTOR CONCEPT

In the days when fixed-size plots represented basically the only type of vegetation inventory, the field installation and the reduction of data to an acre basis were very simple. All one needed to know was the plot radius, diagonal, or length and width, and the per acre conversion factor, found by calculating the reciprocal of the plot area in acres. Then, in the late 1940's horizontal point sampling was born, followed shortly thereafter by the other forms of polyareal plot sampling. The inventory planner's tool kit was greatly expanded by these events but field techniques became more complex and the reduction of data to per acre estimates became a mystery to many people.

Early work at Purdue University regarding the per-acre estimates from various types of point and line sampling, led to what we have called the factor concept. In the broad sense this concept involves four parts:

1. A system of symbolism
2. A system of terminology
3. A procedure for formula development
4. Summary procedures

A table of symbols, first published in 1967 (Beers and Miller) is shown in Table 1. Note that (1) capital letters are used for point sampling while lower case letters are used for line sampling; (2) suggestive lower case letters are used to identify the particular tree characteristic involved; and (3) those factors which are constant and therefore "characterize" the given system are unsubscripted (e.g., F = basal area factor for horizontal point sampling, since in that system one samples with probability proportional to basal area and therefore basal area is the characteristic tree attribute).

Table 1.--Useful symbolism for the application of polyareal plot sampling, i.e. sampling with probability of tree selection proportional to tree size[1]

	Type of Polyareal Sampling				
	Horizontal		Vertical		Units represented by
Item to be symbolized	Point	Line	Point	Line	each tree tallied
Tree factor[2]	F_t	f_t	Z_t	z_t	no. of trees per acre
Basal area factor	F	f_b	Z_b	z_b	square feet per acre
Diameter factor	F_d	f	Z_d	z_d	inches or feet per acre
Quadratic height factor	F_{qh}	f_{qh}	Z	z_{qh}	feet squared per acre
Height factor	F_h	f_h	Z_h	z	feet per acre
Volume factor	F_v	f_v	Z_v	z_v	bd. ft., cu. ft., or cords per acre
Circumference factor	F_c	f_c	Z_c	z_c	inches or feet per acre
Bole surface area factor	F_s	f_s	Z_s	z_s	square feet per acre

[1]Horizontal point: probability proportional to (diameter)^2
Horizontal line: probability proportional to diameter
Vertical point: probability proportional to (height)^2
Vertical line: probability proportional to height

[2]Tree factor = the number of trees per acre represented by each tree tallied.
Basal area factor = the number of square feet per acre represented by each tree tallied.
Etc.

The system of terminology involves only one notion: each tree tallied as a sample tree has associated with it one tree factor, one basal area factor, one volume factor, one height factor, etc., and the word "factor" is defined as the <u>number of units (stems, sq. ft., cu. ft., bd. ft., feet, etc.) per acre represented by each tree tallied</u>.

The formula development for any specific factor proceeds as follows, using horizontal point sampling as an example:

1. Develop a formula for the plot area associated with the general sample tree as a function of the characteristic tree attribute (D_i^2 or BA_i for horizontal point sampling, D_i for horizontal line sampling, etc.)

<u>Example</u>: for horizontal point sampling

$$\text{plot area}_i(\text{sq. ft.}) = \pi R_i^2$$

$$= \pi\left(\frac{D_i}{12k}\right)^2 \qquad (1)$$

where R_i = plot radius in feet

D_i = tree diameter in inches

k = gauge constant = $\dfrac{D_i}{12R_i} = 2\sin\dfrac{\theta}{2}$

θ = gauge angle

2. Obtain the formula for the tree factor by dividing the plot area into the area of one acre.

<u>Example</u>: for horizontal point sampling

$$\text{tree factor} = F_{t_i} = \frac{43560}{\pi\left(\frac{D_i}{12k}\right)^2}$$

$$= \frac{43560(144k^2)}{\pi D_i^2}$$

$$= \frac{10890\ k^2}{\pi D_i^2/576}$$

$$= \frac{F}{BA_i} \qquad (2)$$

where F = basal area factor = $10890\ k^2$

BA_i = tree basal area in sq. ft.

3. Obtain the formula for any other desired factor by multiplying the desired attribute by the tree factor and simplifying.

<u>Example</u>:

$$\text{Basal area factor} = BA_i F_{t_i}$$

$$= BA_i\left(\frac{F}{BA_i}\right) = F \qquad (3)$$

$$\text{Circumference factor} = C_i\left(\frac{F}{BA_i}\right)$$

$$= \pi D_i\left(\frac{F}{\pi D_i^2/576}\right)$$

$$= \frac{576\ F}{D_i} \qquad (4)$$

$$\text{Volume factor} = V_i\left(\frac{F}{BA_i}\right) \qquad (5)$$

$$D^2H\ \text{factor} = D_i^2H_i\left(\frac{F}{BA_i}\right)$$

$$= D_i^2H_i\left(\frac{F}{\pi D_i^2/576}\right)$$

$$= \frac{576\ F}{\pi}(H_i) \qquad (6)$$

After the pertinent factor formulas have been developed and simplified, data summary can proceed very simply: to obtain a per acre estimate in a given classification, say volume per acre for the 20-inch red oak class, one need only add the volume factors (F_V) for all the trees in that classification and divide by the number of points visited. Analogously, to estimate number of trees per acre, sum the tree factors and divide by point count. Other estimates can be obtained using the same procedure.

Foresters familiar with the usual computer processing formulas applied to point sampling inventory data might question the need to develop these individual factor formulas when any per acre estimate can be made more generally by the following:

$$X \text{ per acre at one point} = X_1\left(\frac{F}{BA_1}\right) + X_2\left(\frac{F}{BA_2}\right) + \cdots + X_m\left(\frac{F}{BA_m}\right) \qquad (7)$$

where X_i = the tree attribute of interest

and m = number of sample trees at the point

There are two main reasons why going through the exercise of specific factor formula development can be profitable. First, it facilitates the preparation of convenient tally sheets. The necessary factors can be pre-calculated and entered on the field sheet, enabling rapid data summary requiring a minimum of calculations. Second, and perhaps more important, the development of factor formulas can uncover distinctly superior field

techniques. The way this comes about is suggested by what occurred in formula (6). There, tree diameter completely dropped out of the factor formula, which implies that its measurement or estimation is totally unnecessary. We at Purdue have dubbed this process "obviation".

The most apparent applications of this obviation process come about if we can assume that individual tree volume can be sufficiently well estimated by the formula:

$$V_i = b\, D_i^2 H_i \tag{8}$$

where V_i = individual tree volume (or weight)

D_i = tree DBH

H_i = tree height

b = regression coefficient properly derived for the timber involved

If one then chooses to use horizontal point sampling, diameter obviation is obtained, since

$$F_{v_i} = V_i\left(\frac{F}{BA_i}\right)$$

$$= b\, D_i^2 H_i\left(\frac{F}{.005454\, D_i^2}\right)$$

$$= b\, \frac{F}{.005454}\, H_i$$

Therefore, each foot of height represents $b\,\frac{F}{.005454}$ units of volume per acre and one need simply sum the heights of point sample trees, multiply by $b\,\frac{F}{.005454}$, divide by point count and mean volume per acre has been estimated! The field tally, the field technique, and the summary all have been greatly simplified by obviating diameter.

If the obviation of tree height is desired, one can choose vertical line sampling and develop the volume factor:

$$z_{v_i} = V_i\left(\frac{z}{H_i}\right) = V_i\left(\frac{330q}{H_i}\right)$$

$$= bD_i^2 H_i\left(\frac{330q}{H_i}\right)$$

$$= (b\ 330q)D_i^2$$

where z_{v_i} = volume factor for the i^{th} tree

z = height factor = 330q

q = vertical gauge constant = tangent of the constant gauge angle

Analogous to the previous development we now have height obviation and tree height need not be measured or estimated in the field procedure.

Noting that each of the techniques, horizontal point and vertical line sampling, can obviate one of the variables in the tree volume model ($V_i = bD_i^2H_i$), the thoughtful forester soon begins to wonder if perhaps both variables can be obviated simultaneously! In this way volume per acre could be estimated from tree counts only. Several comments can be made along this line:

1. The combination of horizontal point sampling (i.e., with probability proportional to D^2) and vertical line sampling (i.e., with probability proportional to H) is not physically feasible. And, while the simultaneous application of horizontal and vertical point sampling is feasible, one would be sampling with probability proportional D^2 and H^2 and individual tree volume predictions of the form $V_i = bD^2H^2$ are typically very weak. Therefore, direct combinations of this type to obviate both diameter and height appear fruitless.

2. The recently described (Wiant, 1976) combination of horizontal point and 3-P sampling (Grosenbaugh, 1963), which achieves sampling with probability proportional to both D^2 and estimated H, can be shown to be equivalent to horizontal point sampling with diameter obviation if the measured tree volume is obtained by $V_i = bD_i^2H_i$.

3. In certain situations, volume per acre can be accurately estimated from tree counts alone by a technique called "enumerative inventory" (Hyink, et al, 1977) and described in a forthcoming journal article.

In summary, I can substantiate that over 20 years of teaching and research in point and line sampling at Purdue University have demonstrated the value of the factor concept. It has expedited the learning process for beginners and has led to the development of efficient resource inventories, only a few of which have been described here.

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Specifying Precision in Natural Resource Inventories[1]

David A. Hamilton, Jr.[2]

Abstract.--The cost of incorrect decision should play an important role in establishing inventory precision. A procedure that minimizes sum of costs of obtaining information plus expectations of loss is described. It is demonstrated that, contrary to common practice optimal precision cannot be specified independently of sampling design.

INTRODUCTION

Inventory precision is a measure of the repeatability of inventory results. A statement of precision usually includes two values: (1) the maximum error that is acceptable to the decision maker (confidence interval) and (2) the desired probability of satisfying this criteria (significance level).

Cochran (1963) lists 11 factors or steps in an inventory. I have summarized these into the following four steps required in inventory planning:

1. Development of a clear statement of inventory objectives.
2. Identification of the population to be sampled and the data to be collected.
3. Specification of the desired level of inventory precision (sample size).
4. Selection of an efficient sampling design for collecting this data.

In this paper I will concentrate on the third of these steps--specifying the level of precision. (Actually, none of the steps may be considered independently of the others).

In determining the appropriate level of precision we must first answer questions such as: (1) What decisions are to be made on the basis of the inventory, (2) what information is needed to make these decisions, (3) what impact will errors in information have on the decisions being made, and (4) what impact will incorrect decisions have on the decision maker?

Precision requirements can be determined in many ways. Most of these methods, however, rely heavily on subjective judgments by the natural resource manager. Frequently, this may mean specifying precision at the level that has proven successful for similar inventories in the past. If population variability and intended uses of the inventory information are similar to previous inventory situations for which we have experience, this approach to specifying precision should prove to be adequate. However, if either or both the population variability and the intended uses of inventory information change, this approach will provide very little guidance to the appropriate precision level.

Frequently the desired level of inventory precision is determined by the available funds. Intuitively, this approach appears to be very reasonable. However, inadequate funds may result in poorer estimates of required precision than subjective judgement. In fact, the value of the inventory information may be less than the cost of collecting the information.

Once an optimal precision level has been determined, the literature provides equations for most sampling designs with which to determine the sample size needed to attain that precision. Thus, the usual procedure for determining sample size is to determine what precision level is desired for the inventory and then to use these equations to determine the required sample size. The procedures discussed in this paper are designed to estimate optimal sample size directly as a function of the value of the information that is to be collected.

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To determine sample size in this way one must evaluate the trade-off between the costs and effort required to attain additional precision, and the value or need for the additional precision. There are three major components to be considered in the process of developing these trade-offs. First, one needs a method to determine the value of inventory information. Second, methods of evaluating the costs associated with obtaining information must be considered. Finally, the appropriate method for evaluating the trade-offs in order to select the optimum sample size must be determined.

ALTERNATE METHODS OF PRECISION SPECIFICATION

Hamilton (1970) reviewed four alternative methods for specifying optimal precision levels. These include maximum utility analysis (Raiffa and Schlaifer 1961), marginal utility analysis, inventory control analysis (Horowitz 1965), and minimum cost-plus-loss analysis. Each of these methods of analysis may provide advantages in the development of precision standards for certain types of management situations. However, each of the first three methods has been shown to be a variation of the cost-plus-loss analysis (Hamilton 1970). The rest of this paper deals with the use of cost-plus-loss analysis to determine optimal sample size in a natural resource inventory.

COST PLUS LOSS FUNCTION ANALYSIS

The cost-plus-loss function is the sum of a cost of information function and expected loss function. Optimal sample size is determined by minimizing the cost-plus-loss function with respect to sample size.

The first requirement of this analysis is to develop a cost of information function. This function should include the costs of sampling, the costs of data summarization and analysis, and any other costs associated with obtaining inventory information. Jessen (1942) and Hansen and others (1953) have suggested that a cost function of the form

$$C_t = C(T_2 n + T_1 d\sqrt{n}) \qquad (1)$$

where

C_t = total cost of sampling in dollars

C = hourly cost of the sampling crew

T_1 = time, in hours, required to travel a unit distance between plots

T_2 = time, in hours, required to measure a plot

n = sample size

d = square root of the area of the population from which sample is to be drawn (in units compatible with T_1)

should adequately approximate sampling costs when plots are selected by a systematic sampling design. Other costs of information may frequently be approximated as being proportional to sample size or as fixed costs (costs such as data analysis, data summarization, and data processing).

The second requirement of this analysis is to develop a loss-function that describes the losses that occur when decisions are based on inventory information that deviates from the true population values. The form of the loss function cannot be specified in advance by someone unfamiliar with the decision that is to be made. Thus, the decision maker should be the person most qualified to define the loss function.

In many situations the form of the loss function may be approximated by a quadratic or linear loss function or by some modification of these two basic functions. When such an approximation is adequate, the optimal sample size may frequently be obtained analytically. When more complex loss functions are required to adequately describe the losses encountered, analytical solutions may not exist.

The final requirement of this analysis is to evaluate the distribution of possible inventory outcomes. This distribution is used to evaluate the expected loss resulting from conducting an inventory at a specified level of precision. Expected loss is determined by multiplying the loss associated with each possible inventory outcome by the probability of occurrence of that outcome. The sum of these products is the expected loss. In many situations statistical theory (Central Limit Theorem) permits one to approximate the distribution of inventory outcomes with the normal distribution.

APPLICATION OF COST-PLUS-LOSS ANALYSIS TO FOREST INVENTORY EXAMPLE

The population for this example is a 40-acre stand of old growth Douglas-fir described by Johnson and Hixon (1952). The total board foot volume on each of the 200, 1/5-acre plots that make up the stand is known. In order to expand the scope of the example, two populations were generated from the original Douglas-fir population by dividing each observed volume by 10 and by 100.

The timber is to be purchased for a price determined by multiplying a sample survey esti-

mate of total stand volume by a predetermined stumpage price. In the analysis of the original Douglas-fir population, stumpage prices of \$59.90 and \$22.40 per thousand board feet (MBF) were used (Austin 1968). For the two generated populations, arbitrary stumpage prices of \$20.00, \$10.00, and \$2.00 per MBF were used in order to investigate the impact of changing stumpage prices over a broader range of values.

Sample survey plots are selected by systematic sampling with a random start. The random start is obtained by selecting the first 1/5-acre plot at random from the first k plots ($k = 200/n$). It is assumed that for physical reasons the plots must be visited by traveling only in an east or west direction along the 20 rows of 1/5-acre plots.

The cost of sampling function that results from this constraint may be expressed as

$$\begin{aligned} C_t &= C(T_1(n+1)20+T_2 n) \qquad && 2 \le n \le 20 \\ &= C(420T_1+T_2 n) \qquad && 20 < n \le 200 \end{aligned} \tag{2}$$

A time study conducted by Johnson and Hixon (1952) defined T_1 as 0.03 hours (1.84 minutes) and T_2 as 0.137 hours (8.20 minutes). C is set at \$12.00 per hour. It is assumed that the time and cost factors are applicable to all three populations to be considered in this example.

The sensitivity of precision specification to minor modifications in the functional form of the cost function will be examined by substituting the generalized cost function discussed in the previous section (equation 1) for the cost function developed specifically for this example. The effects of modifications of the parameters of the cost function will also be evaluated.

Since estimates for total stand volume are evaluated as a linear function of the sample mean, the distribution of differences between estimates of total stand volume and the true total stand volume may be approximated by the normal distribution (Madow 1948).

Since the population being used in this analysis is a finite population, there arises a question as to whether the normal approximation is valid for small sample sizes (near zero) and for large sample sizes that approach a complete enumeration of the population.

The use of Monte Carlo techniques (repeated sampling from the population) demonstrated that for samples of size $12<n<188$, the normality assumption is valid. Statistical analysis of the distribution of sample estimates generated by these techniques indicates that deviations from normality outside this range are due to a significant skewness of the population of estimates. The significant skewness implies that the distributions are not symmetrical about the population mean.

Further study of those cases for which the specified optimal sample size fell outside the range for which the normality assumption is valid demonstrated that use of the actual distribution in place of the assumed normal distribution resulted in no differences in the optimal sample size specification for this population.

Two loss functions are considered in this example. The first of these loss functions is an absolute value loss function of the form

$$L_1 = |z-\Theta| D \tag{3}$$

where

L_1 = absolute value loss in dollars

z = inventory estimate of total stand volume in MBF

Θ = actual total stand volume in MBF

D = stumpage price in dollars per MBF

The quadratic loss function is a second commonly used loss function. This function has the form

$$L_2 = (Dz - D\Theta)^2 \tag{4}$$

where

L_2 = quadratic loss in dollars.

The expected values of these loss functions, assuming a normal distribution of possible inventory outcomes, are discussed by Hamilton (1970). These expected values do not depend on the actual total stand volume (Θ). Thus, it is not necessary to know the value of Θ in order to complete the analysis.

These loss functions were arbitrarily selected to permit investigation of the impact of changes in the loss function on optimal sample size. The absolute value loss function describes losses that are proportional to the difference between the inventory estimate of total stand volume and the actual total stand volume. When losses increase at an accelerating rate as this difference increases, the quadratic loss function is more appropriate.

Table 1 summarizes the impact of population characteristics, of stumpage prices, and of loss functions on the specification of optimal precision. The analysis indicates that for this high-value, old growth Douglas-fir stand, it is necessary to measure 100 percent of the stand. This is true for both of the loss functions considered.

The absolute value loss function demonstrates the sensitivity of precision specification to changes in the value of the product being inventoried. In this case, value is expressed as the product of stand volume and stumpage price. As the value of the timber decreases, the required intensity of sampling also decreases.

The same relationship is demonstrated by the quadratic loss function. However, if this loss function is assumed adequate, the analysis implies that no reduction from 100 percent measurement is justified unless the stand is low valued and has little volume.

The very small sample sizes required for the lowest valued, lowest stocked stand further emphasize the fact that when the information being collected is of low value, there is little justification for spending much money or effort to obtain the information.

With the efficient sampling methods available to managers, there are probably very few situations in which a 100-percent sample would be necessary. However, in this portion of the study I did not consider alternative sampling designs. Thus, the example demonstrates the impacts on optimal sample size that result from changes in those factors that describe the costs of gathering information and the losses that occur when decisions are based on inventory estimates that deviate from the true population values.

Table 1.--Optimal sample sizes for alternative loss functions

Population mean volume per plot[1]	Stumpage price[2]	Optimal sample sizes for loss functions	
μ	D	L_1	L_2
18,263	59.90	[3] 200	200
	22.40	200	200
1,826	20.00	101	200
	10.00	64	200
	2.00	22	200
183	20.00	22	200
	10.00	14	163
	2.00	5	33

[1]Board feet.
[2]Dollars per thousand board feet. (MBF)
[3]Sample size of 200 represents complete measurement of the stand.

Precision specification is sensitive to some modifications of the cost function. As the parameters of the cost function change, raising the cost of sampling, the optimal sample size decreases (table 2). However, substitution of the generalized cost function (equation 1) for the function developed specifically for this example (equation 2) resulted in only moderate changes in the optimal sample size. Because of the similarity of the two cost functions, this result should not be considered unexpected. Alternative cost functions that represent a significant modification of the cost structure would be expected to result in significant changes in the optimal sample sizes.

IMPACT OF SAMPLING DESIGN ON OPTIMAL PRECISION

The method used to select sampling units to be measured affects both the expected value of the loss function and the cost of sampling function. The expected value of the quadratic loss function, when we assume the distribution of possible inventory outcomes is normal, may be expressed as:

Table 2.--Sensitivity of precision specification to changes in cost function parameters (absolute value loss function, generalized cost function)

Plot measurement time[1]		Travel time[2]		Cost of sampling crew[3]	
T_2*60	n	T_1*60	n	C	n
4	130	0.5	97	6	143
5	116	1.0	94	7	129
6	105	1.2	92	8	117
7	96	1.84	88	9	108
8.2	88	4	75	10	100
9	83	5	71	11	94
10	78	6	66	12	88
11	74	7	62	13	83
12	70	8	59	14	79
13	67	9	56	15	75
14	64	10	53	16	72
15	62	11	50	17	69
16	59	12	48	18	66

[1]C = \$12/hour, T_1 = 1.84/60 hour, D = \$20.00/MBF, μ = 1,826 board feet.
[2]C_2 = \$12/hour, T_2 = 8.2/60 hour, D = \$20.00/MBF, μ = 1,826 board feet.
[3]T_1 = 1.84/60 hour, T_2 = 8.2/60 hour, D = \$20.00/MBF, μ = 1,826 board feet.

$$E(Dz-D\Theta)^2 \doteq D^2N^2S^2/n \quad (5)$$

where

S^2 = variance of y_i

y_i = plot value of the variable of interest

when a systematic sampling design is used to select plots for measurement. In this work I have ignored the finite population correction. This has no effect on the determination of optimal sample size because the term that would be added to the expected loss function is independent of sample size. Equation 1 is the cost of sampling function that is appropriate for this situation.

If the costs of travel between plots are high relative to the costs of measuring a plot, it may be more efficient to measure a cluster of plots at each sampling location. In this case, the variance of the inventory estimate of the population total of y_i is expressed as:

$$\text{Variance } (Y)=(NM)^2S^2[1+(M-1)\rho]/nM \quad (6)$$

where

Y = population total of y_i

M = number of plots per cluster

N = number of clusters in the population

n = number of clusters measured in the sample

ρ = intracluster correlation coefficient

Thus, the expected value of the quadratic loss function, when we assume the distribution of possible inventory outcomes is normal, may be expressed as:

$$E(Dz-D\Theta)^2 \doteq D^2(NM)^2S^2[1+(M-1)\rho]/nM \quad (7)$$

Equation 5 may be rewritten as:

$$E(Dz-D\Theta)^2 \doteq D^2(NM)^2S^2/nM \quad (8)$$

The expected loss for cluster sampling is greater than the expected loss for systematic sampling by the factor $[1+(M-1)\rho]$.

The appropriate cost of sampling function for cluster sampling may be expressed as (Cochran 1963):

$$C_t=C_1T_2nM+C_2T_1d\sqrt{n} \quad (9)$$

where

C_1 = hourly costs associated with measuring a plot

C_2 = hourly costs associated with traveling from cluster to cluster (plot to plot for systematic sampling)

The cost of sampling function appropriate when systematic sampling is used (equation 1) may be rewritten as:

$$C_t=C_1T_2nM+C_2T_1d\sqrt{nM} \quad (10)$$

Thus, the cost of sampling for cluster sampling is less than the cost of sampling for systematic sampling.

The following example demonstrates the potential impact of sampling design on optimal sample size. Let

D = \$10.00 dollars per MBF

S^2 = 0.02 (MBF)^2

C_1 = C_2= \$12.00 dollars per hour

T_1 = 4/60 hours per chain

T_2 = 16/60 hours per plot

d = 20 chains

M = 4 plots

N = 50 clusters

ρ = 0.1

If we assume that the quadratic loss function is appropriate, the optimal sample size for systematic sampling is n = 144. If we apply cluster sampling with clusters of four plots, the optimal sample size is 43 clusters (total of 172 plots). Cost of sampling is \$652.80 for systematic sampling and \$655.32 for cluster sampling. The expected cost plus loss for systematic sampling is \$1,208.36 while for cluster sampling the expected cost plus loss is \$1,259.97. The variance of the estimate of total volume assuming optimal sample size for the two designs is 5.56 (MBF)^2 for systematic sampling and 6.05 (MBF)^2 for cluster sampling. In this situation all factors indicate that systematic sampling is the optimal design.

Of particular interest is the fact that optimal precision is not the same for the two sampling designs. Optimal sample size for systematic sampling results in a precision of plus or minus 12.6 percent of the mean at the 95 percent significance level while optimal precision for cluster sampling is plus or minus 13.2 percent of the mean at the 95 percent significance level. Since the sampling design affects both the cost of information function and the expected loss function, precision (or sample size) cannot be specified independently of the sampling design.

If we modify some of the parameters of the cost of sampling function to represent a situation more favorable to cluster sampling, this result can be changed.

Let

C_1 = \$12.00 dollars per hour

C_2 = \$24.00 dollars per hour

Then the optimal sample size for cluster sampling is 41 clusters (164 plots), which results in an expected cost plus loss of \$1,363.85. The cost of sampling is \$729.70 and the variance of the estimate of total volume is 6.34 $(\mathrm{MBF})^2$. The optimal sample size for systematic sampling is 132 plots which results in an expected cost plus loss of \$1,396.11. The cost of sampling is \$790.05 and the variance of the estimate of total volume is 6.06 $(\mathrm{MBF})^2$. In this situation cluster sampling is the optimal design even though the variance obtained by cluster sampling is larger than that obtained by systematic sampling. Optimal precision for systematic sampling is plus or minus 13.2 percent of the mean at a significance level of 95 percent while for cluster sampling, optimal precision is plus or minus 13.5 percent of the mean at the 95 percent significance level.

If the intracluster correlation coefficient is increased the variance of the estimate of total volume is increased and thus, expected loss is increased. This results in an increase in optimal sample size.

CONCLUSIONS AND SUMMARY

Factors affecting optimal sample size (precision) include the decisions that are to be made, the characteristics of the population to be sampled, the loss function, the cost of information function, the distribution of possible sample outcomes, and the sampling design. Major changes in loss or cost function may result in significant changes in optimal sample size.

The major difficulty encountered in the application of these procedures is the problem of defining a loss function that adequately describes the losses that the decision maker will encounter. However, if the resource manager has carefully answered the four questions discussed in the introduction, the loss function will be defined.

The cost-plus-loss analysis discussed in this paper provides an efficient method to determine optimal sample size for most natural resource inventories. Even if all the factors needed to conduct this analysis are not available, use of the concepts discussed in the paper should enable the resource manager to improve his capability to determine the appropriate inventory sample size.

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Design of Integrated Natural Resource Surveys[1]

David D. Chapman[2]

Abstract.--Natural resource surveys are integrated to increase statistical efficiency or reduce survey cost. The key to survey integration is the dependent selection of surveys and the use of information exchanged between surveys. Demographic and agriculture surveys illustrate some basic principals of survey integration.

INTRODUCTION

Historically society has given natural resource data a low priority. In the past, society viewed the natural resources as something to be used and consumed, but not intensively managed. This resulted in a natural resource management policy needing, and often desiring, little information; a management system needing only a small, specifically oriented statistical data collection system to support management activities and policy making. The increased demand on all aspects of the natural resources has led natural resource users and managers to the realization that the renewable natural resources unless wisely and efficiently managed are finite and "exhaustible."

The need for intensive natural resource management to cope with increasing demands by resource users creates the requirement by managers and decision-makers for simultaneous information on all aspects of the natural resources. Each manager needs increasing amounts of information with which to make sound decisions. A manager's requirement for information increases with the availability of sophisticated quantitative management techniques. Conversely, the availability of diverse, detailed information causes management policies and techniques to expand to make use of available information. If natural resource managers follow the pattern set by managers in the social and economic areas, they will use and demand more detailed and more frequent information on smaller geographic areas.

Intensive natural resource management requires accurate, timely information in order to make sound management decisions and long-range plans. This requires the design of numerous, often repetitive, surveys for the same geographic area. Because of this need to acquire information through multiple similar surveys over the same area or population in a relatively short period of time, natural resource statisticians seek to find new and better methods to conserve limited survey resources while at the same time achieving a desired degree of survey accuracy. Planned integration of surveys is one method of achieving this goal.

DESIGN OF INDIVIDUAL SAMPLE SURVEYS

To discuss the design of a single one-time survey or the simultaneous design of multiple surveys, a few basic concepts are needed. The purpose of any survey is to collect information on the parameters of the survey population. It is this information on population parameters on which managers base their decisions.

The survey population is a collection or group of elementary units. The elementary unit of the population is the basic unit of the survey. Each survey has at least one type of elementary unit; however, a survey can have two, three, four or more different types of elementary units. When a survey has two or more elementary units, the survey will collect information and estimate the parameters of the survey population associated with each type of elementary unit.

The sample unit is the concept on which the survey sample design is based. A sample

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[1]Paper presented at the Integrated Inventories of Renewable Natural Resources Workshop, Tucson, Arizona, January 8-12, 1978.

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unit is a single elementary unit or a group of two or more elementary units clustered in some way. Associated with the sample unit is a rule connecting each elementary unit with a sample unit. The survey population of elementary units is often an ideal or theoretical population. The sample unit is the mechanism for bridging the gap between a unit which can be observed and selected and the elementary unit to be measured. In simple sample designs, the elementary unit is the sample unit. In more complex designs, where it is either not possibel or not practical to identify all elementary population units, some recognizable unit is chosen as the sample unit. When a sample unit is selected into the sample, all elementary units associated with the sample unit become part of the sample. The collection of all sample units is called the survey frame.

The survey frame and sample units allow the selection of elementary units from the population without the identification of every elementary unit in the survey population. In a one-stage or a multi-stage survey, the initial list of sample units is known before any sample unit is selected. In multi-stage surveys there is a different survey frame and sample unit for each stage of selection. With a multi-stage survey, units in the survey frame at the second stage of selection and above may either be known before the survey begins or identified as part of the enumeration process after the selection of the first-stage sample units. The survey design, in particular the sample design, specifies how the survey frame is used to produce survey estimates.

The design of a single one-time statistical survey involves total survey design. Total survey design refers to the design of all aspects of the survey. The "classical" objective of a statistical survey is either to minimize the total survey error for a fixed expenditure of survey resources or to minimize the cost for a fixed level of survey error. The fundamental goal of a survey design is to minimize the survey error of survey estimates per unit cost. In a more general sense, the goal of an individual survey design is to maximize the information content of the survey. Information in a survey can be considered the reciprocal of survey error. Maximum survey information implies minimum survey error.

A survey design is the total plan for achieving survey objectives and disseminating the information to users. The key to maximizing survey information when survey resources are limited is balancing the cost of each component part of the survey against the amount of error it contributes to the total. In general, the more resources--time, money, and trained statistical personnel--devoted to a portion of the survey, the lower that part's contribution to the total survey error and the greater its contribution to the information content of the survey. When surveys are operated on a limited budget, anything reducing resources in one area while keeping the error constant frees resources either to reduce the error contributed by some other part of the survey or to collect additional information which otherwise would not have been collected.

The sample design is a key to making efficient use of survey resources and collecting maximum survey information. The sample design consists of the sampling plan and the method of estimation. The sampling plan specifies a set of rules for selecting the sample once the survey population is defined. The detailed procedure for identifying the population elementary units to be enumerated can be a combination of both the sample design and the measurement design. The method of estimation specifies the statistical estimator for combining individual sample unit information to estimate the population parameters which represent the objectives of the survey. The sample design for a survey is the combination of the sampling plan and the method of estimation into one procedure.

For a given survey frame and survey population, the optimum sample design is the one which combines a sampling plan and a method of estimation to produce the smallest sampling error. The key to reducing sampling error is the use of available auxiliary information either before or after sample selection. Prior to sample selection, auxiliary information can be used to stratify, to cluster, or to construct probabilities of selection. Information used prior to sample selection is incorporated into the sampling plan and affects the estimation of every characteristic enumerated in the survey. After sample selection, auxiliary information can be used as part of the method of estimation only. In the method of estimation, information can be used as part of an estimator such as a ratio, difference, or regression estimator. A major decision in sample design is where to use available information. The statistical efficiency gained from information changes depending on how it is used and the characteristic estimated.

INTEGRATION OF NATURAL RESOURCE SURVEYS

The need for accurate, timely information for natural resource managers and decision-makers often cannot be met in a single survey. Information, when collected, is collected under a budget restricted in time, money, and trained personnel. The demand for information often exceeds the capacity of a statistical

organization to design the surveys, construct the frames, select the samples, estimate the population parameters, and analyze the results. While different managers need different information, each manager requires information on the same geographic area or survey population. The need for repeated collection of information leads to multiple surveys over the same area.

The need for repeated collection of information creates the requirement on statisticians to design numerous, repetitive surveys on the same geographic area. The task of repeated design of diverse, statistical surveys can tax to the breaking point the often meager statistical resources available to a natural resource organization. The quality and quantity of sample surveys is often limited by the availability of trained personnel to design the sampling plan, select the sample, construct the estimator, and evaluate the results. Lack of coordination between surveys either during the design or the execution results in the inefficient use of survey resources. Combining several surveys into one integrated survey is one approach to making the most efficient use of survey time, money, and, most importantly, trained manpower.

The objective of the design of a single one-time survey is to maximize the information content per unit of cost. The objective of the design of an integrated series of surveys is to maximize the total information in all surveys per unit cost. Surveys are integrated when two or more statistical surveys are conducted using the same set of sample units in such a way that individual surveys lose their separate identities. The goal of an "ideal" integrated survey is either to give the same amount of information for a smaller cost than when surveys are conducted separately or to give a greater amount of information for the same cost as surveys conducted separately.

The integration of a survey sample design requires the statistician who designs the survey to standardize his approach to data collection. The use of one sample unit and a standardized sampling plan reduces the need for resources to construct multiple sample frames. The integration of surveys allows the careful construction of one survey frame. The integration of surveys allows the construction and updating of one list of names and addresses whose use and cost can be shared by several surveys. The integration of surveys allows the use of one set of maps or aerial photographs to be used jointly by several surveys. The integration of surveys allows several surveys to share the cost of expensive detailed map or aerial photograph work to update maps or photographs for sample selection or enumeration. Integration of surveys by locating sample units in the same geographic area in a way which does not affect the validity of each individual survey design can result in many surveys sharing one cost.

When survey sampling plans or estimators are complex, the selection of sample units and the estimation of parameters and their reliability requires considerable work. Integration of surveys allows the preparation of one detailed plan for selection of sample units and the location of the unit of enumeration. Integrated surveys are used in two ways: one statistical, the other operational. Integrated surveys can support each other statistically to improve the overall efficiency of the survey. Operationally, the standardization of sample selection and estimation through integration reduces the survey cost.

Statistical integration of surveys requires that each survey either have a planned relationship in its sampling plans or have an interchange of information in its method of estimation. Surveys integrated with respect to their sampling plans may have either a planned independence or planned dependence between surveys so that the statistical relationship between survey samples can be used to improve the efficiency of survey estimates. When surveys are integrated with respect to the method of estimation, information collected in one survey can be used as part of the method of estimation in another survey. For example, a one-stage survey may select and enumerate clusters of elementary population units. A two-stage sample survey may use the same first-stage sample units and go on to select a sample of elementary units from those enumerated in the first stage. A ratio estimator can be used in the two-stage survey to improve survey estimates using information obtained in the first survey.

In complex or large statistical surveys considerable resources go into the construction of the survey frame. When integrated surveys share a common frame, sample units and probabilities of selection are chosen to be acceptable to all surveys. The practical advantages of integration are offset by a statistical loss in efficiency due to using a compromise sample unit. In part this loss of efficiency can be lessened through the choice of the proper estimator. Ancillary information not usable in the general frame can be used to improve individual survey estimates through the method of estimation.

Surveys can be integrated with respect to three factors: time, space, and content. Surveys can be integrated with all, one, or two of these factors. Surveys can be integrated either partially or totally. Integration in

time implies the same sample units are selected for surveys conducted at different times. Time integrated surveys are commonly used to estimate changes or to improve the statistical efficiency of survey estimates. Integration in space implies sample units in different surveys are related spatially. The establishment of a spatial relationship between sample units of different surveys can reduce the cost of sample selection and location. Sample units in different surveys can be located adjacent to reduce the cost of travel, sample selection, sample location, and preparation of sample materials. Integration in survey content implies sample units from different surveys cover the same subject matter. When different surveys collect information on the same subjects, the information content of the individual surveys can be combined to improve the overall estimates of the population values.

In an integrated series of surveys, an item of major statistical interest is the degree of statistical dependence between surveys. Users of diverse surveys are often not able to evaluate the effect of survey dependence upon estimates or decisions. In situations where information is used from several dependent surveys at one time, decision makers frequently use the data the same whether the survey estimates are independent or dependent. Lack of statistical independence only becomes a problem when estimates from dependently selected surveys are combined in a composite estimator or an index and a measure of the precision is needed. In surveys covering different subjects which cannot be combined little use can be made of information of statistical dependence between surveys.

BASIC APPROACHES TO INTEGRATION

An approach to the integration of surveys is the selection of statistically dependent survey sample units. The survey designer can manipulate two factors in selecting a series of dependent integrated surveys: (a) the sampling plan and (b) the relative time of sample selection and the exchange of information between surveys. Surveys using one sampling plan need only one survey frame and one set of procedures for selecting the sample. Surveys with samples selected and enumerated at one time generally cannot make use of information obtained in one survey to improve estimates in another survey, but the cost of sample selection and location can be reduced. Surveys with samples selected and enumerated at different times can use information obtained in earlier surveys to select the ultimate sample units in later surveys and reduce either the survey error or the survey cost. Three different approaches to integration are the use of:

(1) One common sampling plan, with samples selected at one time

(2) Different sampling plans, with samples selected at one time

(3) Different sampling plans, with samples selected at different times with an exchange of information between surveys

Each approach has merits in given survey situations. The best approach to use depends on the specific survey conditions.

Sample Selection

When a series of sample surveys has the same sampling plan, a major savings in resources can be achieved by selecting the sample surveys dependently. The key is to find a method of dependent sample selection which selects surveys with the same common sampling plan. Each survey must have sample units selected under the sampling plan that would have been used if if had been selected independently.

There are many different ways to select dependent sample surveys from the same survey frame with the restriction that the same sample unit will be in only one survey. One method of achieving this is to select one survey sample and to link all the sample units of other surveys to it. The initial survey sample, which will be called the master sample, should be the sample with the largest number of sample units. The use of this method will be described with respect to systematic random sampling. Systematic sampling is used because it is a design widely used and easy to illustrate. The approach is valid, but slightly more complicated, for other sampling plans.

A survey frame arranges all sample units in the population in a definite order and attaches a unique identifier to each sample unit. Each sample unit in the frame can be considered numbered from 1 to N, the number of sample units in the frame. This sample unit number identifies the order of the sample in the frame and serves as the basis for identifying the sample units to be selected into the sample. The order of the sample unit in the frame will be called the sample unit selection number. When a random number equal to the sample unit selection number is picked, that sample unit will be part of the sample.

The relationship between the sample unit selection numbers of the initial sample or master sample and the sample units of the i'th survey is given by the following:

Sample Unit Selection No. Survey i	=	Sample Unit Selection No. Master Sample	+	Dependency Constant Survey i

The sample unit selection number for the initial or master sample is determined by the sampling plan used to select the master sample. The dependency constant is the number used to link the sample units selected in all other surveys to the master sample. Two factors influence the choice of the dependency constant: the sample design and the sample size.

When all surveys have the same sample size, any set of sample units is identified by first selecting a set of sample units--the master sample--according to the sampling plan. The dependency constant is added to the sample unit selection numbers of the master sample to generate a new set of sample units of equal size and with the same sampling plan. In this procedure, problems can occur two ways: (a) a generated sample unit selection number may be greater than the number of units in the frame, and (b) in certain sample designs the generated sample unit selection number may duplicate a sample unit number already selected in an earlier survey. In situations where the generated sample unit selection number exceeds N, the number of sample units in the frame, a sound approach is to assume the survey frame is circular and create a new number by subtracting N from the generated number. In situations where the sample unit selection number may be duplicated, a rule should be developed to identify a new sample unit selected. Many rules are possible, a simple rule would be to pick the nearest free sample unit selection number which is larger than the duplicate.

When surveys have samples of different sizes, the selection of dependent samples becomes more complicated. If the new dependent survey is selected with a systematic sample which has a sample interval which is an integer multiple of the sampling interval of the master sample, the new sample is selected by first selecting a survey sample of equal size to the master sample. Select a random number, say r, between 1 and the integer which is a multiple of the new and master sample intervals, then the new sample units will be every r'th sample unit selected. If the new survey either is not a systematic sample with a sampling interval which is an even multiple of the master sample interval or is not a systematic sample at all, the best procedure may be to select a full sample and then use a random number table to select a subsample of the appropriate size.

The choice of the dependency constant determines the relationship between surveys. In a survey with a systematic sampling plan, a dependency constant of zero will give a survey with the identical sampling units as the master sample. If dependency constants are picked at random from the sample interval, without repeating the constant, the integrated survey would give an interpenetrating series of systematic samples. When the sample units in the survey frame are arranged in a definite pattern, a purposive selection of values for the dependency constant of dependent surveys has practical applications.

In many surveys, sample units in the frame have a definite pattern or arrangement. In area frames the sample units are often arranged in geographic order. Sample units close together on the list are close together on the ground. The choice of the dependency constant can be used to force sample units in different integrated surveys to be either close together or far apart. Each may have advantages. In an area frame choosing a dependency constant of 1 or 2 requires that sample units in the two integrated surveys be adjacent. Picking dependency constants close to the value of the sampling interval divided by the number of integrated surveys will spread sample units over the entire frame and make sample units in different integrated surveys as far apart as possible.

Time of Sample Selection and Interchange of Information

The time of sample selection and the interchange of information between surveys can be used to construct an efficient integrated series of surveys. Samples selected at the same time can be constructed to statistically support each other. The statistical support may be in the form of either combining the results of two or more surveys to produce one estimate or using information collected in one survey to improve the statistical efficiency of information collected in another survey. Surveys selected at different times can be constructed so that two surveys share the same first-stage sample units and one of the surveys uses information collected on the first-stage sample units as the basis for a second-stage of sample selection.

In surveys selected and enumerated at the same time there is no opportunity for the interchange of information between surveys. Statistical support is planned on the basis of the subject-matter content of the different surveys. For some sample units information is obtained on all items; for others, information is obtained on only a portion of the sample items.

In surveys selected and enumerated at different times, information collected in the earlier surveys can be used in the later surveys. The usual procedure is that a sample is selected and the first-stage sample units enumerated. The first-stage sample unit is often a cluster of elementary population units.

Information is obtained on all elementary units related to sample units. This information can be used in later surveys in three different ways: (a) to stratify elementary units in the selected sample units, (b) to assign the probability of selection of the elementary units in a second stage of selection, and (c) to construct the method of estimation after a second stage of selection.

EXAMPLES OF INTEGRATED SURVEYS

The basic principals of the integration of surveys have been applied and, in some cases, developed in areas outside the field of natural resource management. An integrated survey can be characterized by its sampling plan, by the interchange of information between surveys, and by the relative time of sample selection. Different combinations of these factors give different methods of integration for a series of surveys. Examples of integration can be found in the demographic and agriculture surveys conducted by the Bureau of the Census of the U.S. Department of Commerce and the Statistical Reporting Service of the U.S. Department of Agriculture. Several of these surveys illustrate some of the basic principals of integration.

General Purpose Household Surveys

The general purpose household surveys conducted by the Bureau of the Census are examples of an integrated series of surveys with a common sampling plan where survey samples are selected at one time. General purpose household surveys are used to collect basic information on the population of the United States--information on such subjects as labor force, housing, health, and income.

In the survey design of general purpose household surveys based on the 1960 Census of Population and Housing, all counties in the United States are grouped into clusters of one or more contiguous counties called primary sampling units (PSU's). The primary sampling units are divided into strata. A sample of primary sampling units is selected from each strata with a probability based on the number of households and the number of individuals in group quarters in the 1960 census. Within each selected PSU a frame is constructed to select a sample of segments--clusters of 4 to 6 households. The frame in each PSU consists of each enumeration district in the primary sampling unit arranged in geographic order with a measure of the number of segments in the enumeration district.

For an individual survey a sample of households is selected from each PSU frame by selecting a systematic sample of enumeration districts with probability proportional to the estimated number of segments in the enumeration district. A random start is selected by picking a random number from 1 to the systematic sampling interval. Every enumeration district whose cumulative size corresponds to the random start or the random start plus an integer multiple of the sampling interval is identified as containing a sample segment. Enumeration districts with sample segments are divided into the appropriate number of segments and a probability of sample of segments is selected. All households in a segment are enumerated.

The identification of enumeration districts which contain sample segments are made simultaneously for the Current Population Survey (CPS), the Health Interview Survey (HIS), the Quarterly Housing Survey (QHS), and the March Supplementation to the Current Population Survey. Enumeration districts selected for the Current Population Survey determine the location of sample segments for all other surveys. The location of sample segments for the other surveys--HIS, QHS, March Supplementation to the CPS and 16 reserve samples--are located relative to the CPS sample units. Survey samples are specified as being a given distance on the sample frame from a selected CPS sample segment.

The Current Population Survey

The Current Population Survey (CPS) is a monthly survey to estimate unemployment and general labor force characteristics. One feature of the sampling design is the use of a rotation system to change the sample over a 10-year period. The selection of samples for the rotation is described in The Current Population Survey: A Report of Methodology (U.S. Bureau of the Census, 1963).

> "The use of a rotation system requires the periodic selection and preparation of material for additional samples. It would be possible to select each of these samples completely independently,...However, this would be an extremely costly and inefficient plan, for obvious reasons.
>
> "The plan actually adopted for the development of additional samples had the following important features:
>
> 1. All samples are selected from the same set of PSU's.
> 2. No sample contains a USU [ultimate sample unit or segment] used in a previous sample.
> 3. Additional samples take advantage of geographic and field work done in connection with previous samples.

"Obviously, features 1 and 2 could not both be maintained indefinitely, since all of the USUs in the fixed set of PSUs would be used, or 'exhausted.' However, the within-PSU sampling fractions are small enough that this is not a practical limitation....

"Consider a sample PSU which has been assigned a measure of size of 1,100 USUs and requires a sampling fraction within the PSU of 1 in 100. Assume that this PSU has been completely divided into USUs [segments] and that they have been numbered from 1 to 1,100, using a geographic order....The initial sample of 11 USUs would have been selected by choosing at random one of the first 100 USUs and taking every 100th USU thereafter.

"Under the plan used, the second sample would consist of the 11 USUs immediately following the USUs in the first sample, the third sample would consist of the 11 USUs immediately following those in the second sample, and so forth....

"One feature of this system of generating successive samples by substituting the 'next' USU for each USU in the current sample is that the act of selecting the initial sample completely identifies the additional samples needed for subsequent use. Furthermore, the 'next' USU is usually located in the same sample ED and block, (where 'block' is used to identify a primary subdivision of an ED), and so the amount of geographic and field work required to designate the second and succeeding samples is considerably less than that required for the initial sample or for a sample selected independently of the previous one."

The 1970 Census of Population and Housing

The 1970 Census of Population and Housing is an example of an integrated set of surveys. Information on age, sex, race, marital status, and relationship to head of the household is collected on every individual in the United States. Additional information on education, ethnic origin, employment, income, residence, and other characteristics is collected on a sample basis. Sample information is collected on either 20-percent, 15-percent, or 5-percent of the population. The Procedural History of the 1970 Census of Population and Housing (U.S. Bureau of the Census, 1976) describes the relationship of sample surveys in the 1970 census.

"The basic sample for the 1970 Census of Population and Housing was a 20-percent sample selected from the census listing of housing units...The 20-percent sample was subdivided into a 15-percent and a 5-percent sample: Every fourth 20-percent sample unit...was designated as a member of the 5-percent sample and the remaining sample units became the 15-percent sample. Two different types of sample questionnaires were used, one for the 5-percent and one for the 15-percent sample units. Some sample population and housing questions appeared on both the 5-percent and the 15-percent questionnaires, and these made up the 20-percent sample items. Other questions appeared only on the 15-percent or on the 5-percent questionnaires.

"Whether a question was asked on a 100-percent basis or on a sample basis depended on the size of the area for which statistics were needed and the anticipated amount of detailed cross-classification in the tabulations. Information required for apportioning representation in congress and other lawmaking bodies, and that needed for city block statistics, was collected for all persons and housing units. Information to be tabulated for such areas as census tracts and most counties was collected on a 15- or 20-percent sample basis. The 5-percent sample provided statistics for larger cities, standard metropolitan statistical areas, larger counties, and states as well as for the nation and its regions."

"The subdivision of the 20-percent sample into 15-percent and 5-percent subsamples was done, despite the increased operational difficulties, to accommodate additional subjects with the available resources and without imposing an unreasonable burden on a particular householder."

The 1970 Census of Population and Housing could be considered four separate surveys: (a) a complete enumeration, (b) a one-stage 20-percent sample of individuals and housing units, (c) a two-stage 15-percent sample of population and housing units, and (d) a two-stage 5-percent sample of individuals and housing units. All individuals in the two-stage samples are in the one-stage sample. All individuals and housing units in the one-stage sample are in the complete enumeration. The complete enumeration in the census gives statistical support to each of the sample surveys through the estimation procedure. A complex estimation procedure related to ratio estimation is used to increase the statistical efficiency and the comparability of estimates for the 100-percent, 20-percent, 15-percent, and 5-percent surveys.

The June Enumerative Survey

An area frame provides a complete survey frame for sampling agricultural activities. Any agricultural activity can be represented in a survey where every unit of land has some positive probability of selection. The June enumerative survey, an area frame survey conducted by the Statistical Reporting Service of the U.S. Department of Agriculture, and related area frame surveys is an example of an integrated series of surveys. The basic design of the June enumerative survey and other area frame surveys has been described by the Statistical Reporting Service (1975).

> "...all land [in the United States] prior to sampling is first classified according to use. The stratification is based on extent and type of farming...In addition to land use stratification, geographic stratification is frequently used to separate differing agricultural areas.
>
> "Segments are of a predetermined size, with segment counts associated with each area delineated on maps according to size of area....
>
> "Segment selection has generally followed a systematic-sample approach where the frame listing is arrayed geographically. Recently, interpenetrating sample designs have been used. Interpenetrating designs utilize several smaller independent samples, and have more sample flexibility and advantages in computing sample variation. They also fit well with a sample rotation scheme....
>
> "All selected segments are visited annually about June 1 for the June enumerative survey to ascertain planted crop acreages and inventories of hogs and cattle, and to classify operations for purposes of subsampling for subsequent surveys. All separate land operating arrangements are delineated within the segments and are referred to as 'tracts.'...
>
> "Sampling for several subsequent area frame surveys uses the June information for classifying tracts. The classifications made are utilized as strata for second-stage sampling. Tracts are then subsampled from each statum at varying rates according to their information potential. The December enumerative survey is the largest survey of this type and focuses on fall-seeded crops and livestock inventories. A large portion of the tracts with wheat and livestock in June are selected. Nonagricultural tracts are sampled very lightly.
>
> "Somewhat more difficult are the theoretical concepts associated with subsequent area frame surveys in which all June tracts are first classified into strata and then subsampled. Although it is a two-stage sample design, the second stage of sampling is not confined to primary sampling units, as it is in cluster sampling. Instead, the second stage of selection is among all tracts classified according to predetermined criteria using the June information. With this sampling scheme it is quite likely that some segments will have no tracts selected in the sample. Unbiased direct-expansion estimates can still be generated by associating the probabilities of selection (probabilities at the first stage of selection multiplied by probabilities at the second stage) with the data for each tract sampled. The difficulty arises in computing sampling errors....
>
> "Ratio estimators are...used for surveys based on subsamples of June area tracts. The ratios are computed by relating current data to June data. The June enumerative survey direct-expansion estimate becomes the base for computing a ratio estimate. These estimates are particularly useful for the July acreage update survey where correlations are very high between actual planted acreages and those reported during the June enumerative survey (which in some cases are intended plantings)."

The June enumerative survey serves as the basis for several related two-stage sample surveys. The June enumerative survey is a one-stage survey and the information collected is the basis for the stratification and sample selection of specialized characteristics in later surveys. The July acreage update survey and the December enumerative survey which emphasizes livestock and objective yield surveys are examples of surveys integrated with the June enumerative survey.

NATURAL RESOURCE APPLICATIONS OF INTEGRATED SURVEYS

Integrated surveys have direct application to the collection of natural resource information. The type of integration procedure used depends on the survey methodology available and whether the surveys are to estimate general purpose characteristics possessed by most of the population or to estimate special characteristics possessed by relatively few members of the population.

Information of a general nature which needs to be collected repeatedly over time can

often be best collected using multiple dependently selected surveys. These surveys could be surveys on different subjects or surveys on the same subject at different times. When natural resource surveys are repeated over time, the problem of locating sample units for remeasurement can be considerable. Failure to relocate sample units disrupts the data collection and data processing activities of a survey. If sample units for unrelated surveys were selected dependently and forced to be close together, the use of more exact, but more costly, methods for relocating sample units could be justified. When different survey sample units were close together, the cost of travel, enumeration, and the preparation of sample materials may be reduced.

The statistical efficiency of many natural resource surveys could be increased by integrating surveys with a general purpose natural resource "census" with data available on a small area basis. This natural resource "census" could be conducted using remote sensing imagery. Remote sensing data could be used to stratify, to construct probabilities of selection and to be incorporated into the estimation procedure of general and special purpose surveys.

Surveys can be integrated not only with respect to the sample design but to all parts of the survey design, the measurement design, the data processing design, and the publications design. In the context of total survey design, the definition of an integrated survey can be generalized to include two or more surveys conducted in such a way that individual surveys lose their separate identities with respect to one or more of the following: sample design, measurement design, data processing design, or publications design. Generalized integrated surveys are surveys indistinguishable with respect to one or more portions of the surveys. Resources saved through integration can be used to reduce survey cost or increase information.

Intensive management of natural resources requires managers to seek information needed to make sound decisions. Long-term, planned integration of natural resource surveys is one method of collecting diverse information repeatedly over time and controling survey cost. While not all surveys lend themselves to integration, surveys collecting general purpose information and many surveys collecting special purpose information on the same area can be incorporated into the framework of an integrated series of surveys. In the integration of multiple natural resource surveys, statistical independence among surveys is sacrificed to achieve a reduction in survey cost. This lack of independence between surveys has little practical effect on how the data are used. The final effect of the integration of multiple statistical surveys is to stretch survey resources so that information which otherwise would not be collected is collected and used.

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Bayesian Theory and Multi-Resource Inventory[1]

Alan R. Ek and James N. Issos[2]

Abstract.--Bayesian concepts and estimation procedures are reviewed as a supplement to sampling theory approaches to inventory. Emphasis is placed on the identification of useful prior information. The relationship between stratification and the gains possible from Bayesian approaches using past surveys for prior information are discussed. Results from empirical comarisons of Bayesian and sampling theory approaches to basal area and type area estimation are also presented.

INTRODUCTION

Forest inventory efforts have traditionally relied heavily on prior information in survey design. Examples are the use of knowledge on population variability to develop appropriate sample sizes, field plot configuration and field plot layout, i.e., random or systematic. Estimation may also be facilitated by use of aerial photographs to stratify a population into species, size and density classes. We may further use prior information such as aerial photo based timber volume estimates as an inexpensive covariate in double sampling with regression or stratification where more precise observations are made on a ground subsample of the photo plots. In all of these cases, however, we have used a traditional sampling theory approach. That is, once the sample data is collected, only that data is used in computing estimates.

The intent of this paper is to illustrate how we might use a Bayesian approach to incorporate prior information, in distributional form, into our estimates to improve precision. As will be shown, the Bayesian methodology is particularly helpful where sample sizes are small and there exists much prior information. Such situations are common in the inventory of small tracts or subsets of large tracts.

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Bayesian methodology has been applied to only a few problems in forestry. This is due to both formidable computational requirements of Bayesian statistics and because it differs conceptually from what most of us have been taught: the traditional sampling theory approach. Consequently, a brief discussion of Bayesian and sampling theory approaches is given below. Later computer programs are described for implementing the Bayesian approach and results of empirical trials are presented. Suggestions are then made for survey design to take greater advantage of prior information.

BACKGROUND

Non-Bayesian Inference

In sampling theory population parameters are assumed fixed and inferences about them are made by considering the sampling properties of selected functions of the observations called estimators. That is, we assume that $\tilde{y} = (y_1, \ldots, y_n)$ is a vector of n observations whose probability density function $f(\tilde{y}|\theta)$ is completely known. Then any function $g(\tilde{y})$ of the data that gives some idea of the value of θ may be called an estimator. Usually a very large number of possible estimators may be devised and we choose among them according to criteria established for bias, precision, consistency, etc. Readers should be aware that we sometimes choose biased estimators over unbiased ones as the former can have smaller mean squared errors. Detailed discussions of estimator derivation and properties are given by Rao (1965).

Bayesian Inference

In contrast to sampling theory approaches, Bayesian inference considers the parameters to be random variables and inferences are made by

considering their distributions conditional on fixed data. Specifically, we assume as in the non-Bayesian section that $\underset{\sim}{y} = (y_1, \ldots, y_n)$ is a vector of n observations whose probability density $f(\underset{\sim}{y}|\theta)$ depends upon the population mean θ. In addition, we assume that θ itself is a random variable with a probability density $p_o(\theta)$. Then

$$f(\underset{\sim}{y}|\theta)p_o(\theta) = p(\underset{\sim}{y},\theta) = p(\theta|\underset{\sim}{y})f_1(\underset{\sim}{y}).$$

So given the observed data y the conditional density of θ is

$$p(\theta|\underset{\sim}{y}) = \frac{f(\underset{\sim}{y}|\theta)p_o(\theta)}{f_1(\underset{\sim}{y})} = c \cdot f(\underset{\sim}{y}|\theta)p_o(\theta) \quad (1)$$

where $\frac{1}{c} = \int f(\underset{\sim}{y}|\theta)p_o(\theta)d\theta$.

Equation (1) is usually referred to as Bayes' theorem. In this expression, $p_o(\theta)$ indicates what is known about θ before sampling or without knowledge of the data. Thus this term is called the prior density or distribution of θ. The term $f(\underset{\sim}{y}|\theta)$ is the conditional density of $\underset{\sim}{y}$ given θ. Given the data $\underset{\sim}{y}$, $f(\underset{\sim}{y}|\theta)$ in equation 1 may be regarded as a function of θ rather than y. With such an interpretation this term is called the likelihood function of θ for given $\underset{\sim}{y}$. The term $p(\theta|\underset{\sim}{y})$ indicates what is known about θ given knowledge of the data and is called the posterior density or distribution of θ. Equation (1) may thus be expressed as

$$\text{posterior distribution} \propto \text{likelihood} \times \text{prior distribution} \quad (2)$$

As an example of the use of this approach for point estimates, the population mean may be estimated as the mean of the posterior distribution. Confidence intervals may be obtained from an examination of the posterior distribution. Note, however, that these intervals may not be symmetrical about the point estimate under consideration. A more detailed discussion of confidence interval concepts will be provided by a journal article in preparation.

Priors for Bayesian Inferece

When it is reasonable to regard θ as a random variable and the prior distribution is exactly known, i.e., we know both the distribution form and parameters, Bayesian methods are not considered controversial. Bayes theorem is then an explicit and very useful tool for combining old and new information. Unfortunately, exactly known priors have seldom been available. Two approaches that have been used in lieu of exact priors are described below.

Non-Informative Priors:

When little or nothing is known about a parameter in question, non-informative or locally uniform priors are often used (see Box and Tiao 1973). Mention of such priors goes back to the time of Bayes {1763}. A non-informative prior is essentially one which provides little information relative to what is expected to be provided by the planned sample. In many cases, however, inferences made by using the Bayesian non-informative prior approach are the same as those obtained from non-Bayesian methods.

Empirical Priors:

Empirical priors were introduced by Robbins (1955). Assume as in the earlier section on Bayesian inference that $\underset{\sim}{y} = (y_1, \ldots, y_n)$ is a vector of observations whose probability distribution $f(y_i|\theta)$ depends upon θ and that θ itself has a probability distribution $p_o(\theta)$. Now consider the case where $p_o(\theta)$ is unknown and suppose that certain "past" observations, (y_1, θ_1), (y_2, θ_2), ..., (y_n, θ_n) are available where the θ_i's are independent random variables from the prior $p_o(\theta)$ and y_i is a random observation from an exactly known $f(y_i|\theta)$ density. If the θ_i's themselves are observable and n is large, a histogram of the θ_i's is an appropriate prior for estimating unobserved θ_i. In most cases, however, only estimates of θ_i, say y_i are available. Intuitively the y's should provide some information about $p_o(\theta)$, however, and in fact this is true. The resulting approximation of $p_o(\theta)$ based on this concept has been termed an empirical prior. Unfortunately, the general problem of finding $p_o(\theta)$ given $f(\underset{\sim}{y}|\theta)$ and the y_i's is usually difficult. Conversely, when a solution is possible and n is large, an empirical prior is essentially as good as an exactly known prior. Maritz (1970) is a basic reference for empirical prior approaches.

Despite the difficultly noted above, it is evident that Bayesian approaches are receiving increased attention. Bayesian techniques have been suggested for stratified sampling problems (Ericson 1965) and they are being investigated for estimation of classifier parameters in the interpretation of satellite remote sensing data (Lin and Minter 1976). It is also constructive to note the trend in decision theory toward methods which allow use of subjective estimates of probabilities, i.e., Bayesian techniques (see, for example, de Neufville and Stafford 1971).

CONSTRUCTION OF BAYESIAN ESTIMATES

The Bayesian approach has two important steps. The first is the derivation of the prior $p_o(\theta)$. The second and least difficult step is the combining of prior and new information distributions. The latter step can be handled by numberical integration as described in computer programs noted below. The first step allows many possible approaches. The four discussed here are best described in the context of a forest inventory example.

Consider a forest stand A of a known cover type commonly occurring within a recently inventoried ownership. The objective is to estimate the mean basal area per acre (θ) of stand A. An appropriate prior distribution $p_o(\theta)$ for stand A would be the distribution of mean stand basal area for the other stands of the same type within the ownership. Unfortunately, the true stand means of the other stands are rarely known. As a first alternative, however, we might use the distribution of the sample plot basal area per acre values (X_{ij}) from the other stands as a somewhat conservative empirical prior for stand A. Here X_{ij} is the basal area per acre for the jth plot in the ith stand. This prior can be interpreted as a conservative approximation of how much we know about θ given the forest type of stand a. The rationale for this prior is that it will usually have the same mean but a larger variance than the distribution of true stand means. Consequently, it might be expected that k percent confidence intervals would include true values more than k percent of the time.

A second alternative is to develop what we call a modified empirical prior using an approach similar to that outlined by Robbins (1955). In this case the prior $p_o(\theta)$ is defined by equation 3 below with $f(\theta|\mu,V^2)$ as an arbitrary density having unknown mean μ and variance V^2. The density $f(\theta|\mu,V^2)$ is taken here as a beta function. The density of μ and V^2 are then estimated by Bayes theorem and a non-informative prior approach using numerical methods and the X_{ij} observations noted above. The mean μ of $p_o(\theta)$ is usually found to be the mean of the X_{ij}. Once the posterior density $p_{\mu,V^2}(\mu,V^2)$ is found, $p_o(\theta)$ follows as

$$p_o(\theta) = \int_{\mu}\int_{V^2} f(\theta|\mu,V^2)\, p_{\mu,V^2}(\mu,V^2)\, d\mu dV^2 \qquad (3)$$

For large sample sizes and numbers of stands, this prior should be a close approximation to the actual distribution of the θ_i. Details of the derivation of expression (3) in the context of forest inventory are developed in the previously mentioned journal article in preparation. The procedure is also presented in FORTRAN code by Issos, et al. (1977). The latter report provides batch and interactive Bayesian estimation procedures for a wide range of inventory problems.

Two other priors considered are arbitrary bounds (equivalent to a locally uniform prior) and a previous estimate with its associated normal distribution.

It is, of course, desirable to choose a prior with a small variance. The disadvantage, however, is that unless they are carefully constructed, resulting confidence intervals may be inaccurate (i.e., confidence intervals may contain true values less frequently than expected). The four priors considered here were choosen largely because of the range of simplicity and precision they provide, the availability of such information in forestry and for the degree to which they exclude illogical, e.g., negative estimates.

The operational approach used here involves repeated application of Bayes theorem (equation 1). Given the variable of interest θ, one of the above prior distributions $p_i(\theta)$, say a modified empirical prior, is first developed. This distribution is considered to represent knowledge about θ prior to observing a statistic or estimate y_1. The form of $f(y_i|\theta)$ is assumed known. Bayes' theorem is then used to compute $p_{i+1}(\theta)$ which summarizes the knowledge about θ given y_i. Then using $p_{i+1}(\theta)$ as a prior distribution of θ and observing another statistic y_2, $f(y_i|\theta)$ is taken as known and used with Bayes' theorem to compute $p_{i+2}(\theta)$. Each time this is done a better estimate of θ is usually obtained. For example, if $p_i(\theta)$ and $f(y_i|\theta)$ are both normal then

$$1/\sigma^2_{i+1} = 1/\sigma^2_i + 1/\mathrm{Var}(y_i|\theta) \qquad (4)$$

This means that $\sigma^2_{i+1} < \sigma^2_i$. Even when the prior and the likelihood are not normally distributed relation (4) is usually approximately true. An example of prior refinement would be the incorporation of the third and fourth types of prior information noted to form $p_{i+1}(\theta)$ and $p_{i+2}(\theta)$, respectively.

Jeffreys (1961) provides considerable rationale for the approaches to constructing priors and estimates that we have used here.

SAMPLE TRIALS

Stand Basal Area Estimation

In most management oriented inventories some or all of the subject stands are sampled with from one to twenty plots. In such cases there are usually enough plots to provide precise estimates of type mean volumes, etc., but not enough to provide useful precision at the stand level. The costs and logistics of more intensive sampling within stands is usually prohibitive. The consequences of this situation have been the acceptance of low levels of precision for stand level estimates and/or a search for alternative sampling and estimation methodology. The Bayesian approach outlined above and implemented below is one very effective alternative.

The data for this illustration consisted of plot records and type mapes for a recent intensive inventory of a 30,000 acre industrial forest block in northern Wisconsin. The data consisted of systematically located plots (15 BAF bitterlich point samples) set approximately ten chains apart using points on a randomly located square grid. The grid was positioned randomly over each compartment (an administrative grouping of geographically related stands). Henceforth these systematically located plots are treated and referred to as random plots. Justification for this treatment is given by Payandeh and Ek (1971) and Sayn-Wittgenstein (1966).

Using the conservative prior approach, estimates were developed for basal area per acre (θ) for each stand in the major cover types (species-size class categories). Estimates were based on the following kinds of prior (P) and random sample plot information singly and in various combinations.

- R Random plots in subject stand;
- P_t Type prior based on the distribution of all random plots in a cover type, i.e., a conservative empirical prior;
- P_b Type bounds prior based on an arbitrarily chosen interval usually slightly wider than the observed range of the random plots in a cover type.

Using the modified empirical prior approach, P_t was replaced by P_e, the latter representing a more precise characterization of the distribution of θ. These estimates were then compared and evaluated in terms of bias and confidence interval widths. Non-Bayesian estimates or confidence intervals were based on only the R random plots within a subject stand.

An illustration of the output from the Bayesian estimation approach is shown in Figure 1. The Bayes estimate of basal area per acre for the subject stand was developed from the programs noted above. The modified empirical prior shown was based on 14 plots from 6 stands, i.e., 2-3 plots per stand. The non-Bayesian estimate (a t distribution) was based on three plots in the subject stand.

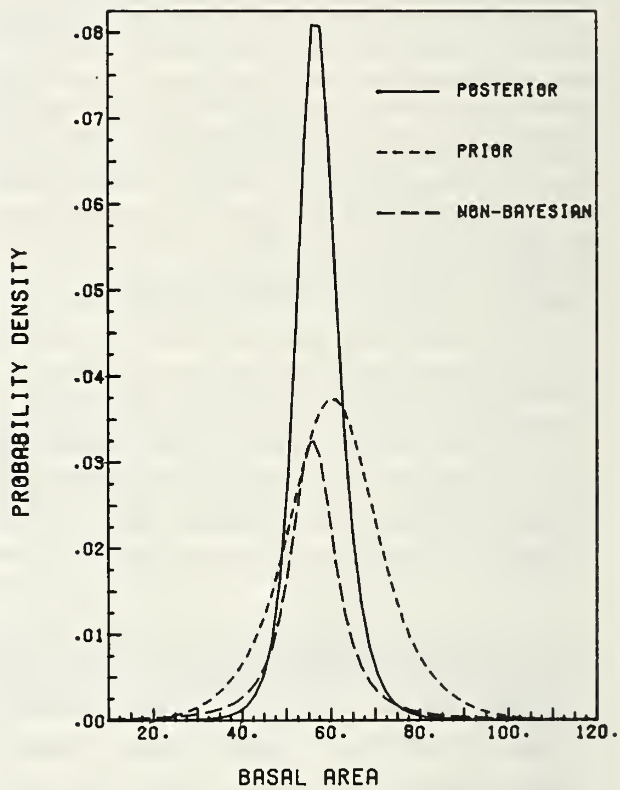

Figure 1. Comparison of Bayesian and non-Bayesian estimates of stand basal area (sample output from Issos et al. (1977)).

In this case, the Bayesian 95 percent confidence interval is .552 as long as the non-Bayesian interval. Here the prior was combined with the non-Bayesian estimate by multiplying ordinates of the former by corresponding ordinates of the latter. Dividing these products by the appropriate sum leads to a new set of

ordinates -- the posterior distribution or Bayes estimate. Confidence intervals were then obtained by an iterative distribution slicing routine.

Additional sample results for the conservative and modified empirical priors are shown in Table 1 for a common type in the industrial forest data (cover type 9: upland hardwood stands of size class 6 - 13.5 inches Dbh).

Conservative Empirical Prior Results

The results in Table 1 for the conservative empirical prior approach (P_t) indicate substantially smaller confidence intervals for random sample sizes of $n \leq 3$ than use of the random sample data alone. The lack of large gains for the stands with 7 or 8 random plots is due to the sampling intensity. It is important to note, however, that further breakdown of the type prior by aerial photo based stand density classes would very likely have narrowed the prior distribution. It is also noteworthy that Bayesian estimation is the only approach that provided a confidence interval for the stand lacking at least two random plots. Further, the Bayesian approach precluded illogical (for example, negative) confidence intervals.

A limited examination of the accuracy of these confidence intervals was reported in an earlier paper.[3] Briefly, that examination suggested that the Bayesian confidence intervals using the conservative prior approach were accurate. Since they should, in fact, be more conservative than those for the modified empirical prior, further analyses have emphasized the more precise prior.

Modified Empirical Prior Results

Results for the modified empirical prior (P_e) are also presented in Table 1. The reader can see that substantial gains result from using this prior for even sample sizes of up to 19 random plots. For small random plot samples, say less than 3 observations, use of the modified empirical prior is the difference between little or no information and useful precision. For samples of size 4-12, the prior provides about as much information as the sample, that is, it significantly shortens the confidence intervals.

The accuracy of these confidence intervals was assessed in two ways. First the prior was used to develop confidence intervals for the X_i. or sample stand means for the 94 stands comprising the cover type. Resulting confidence

[3]Ek, A. R. and J. N. Issos. 1976. Bayesian estimation methodology for forest inventory. Paper presented at Midwest Mensurationists meeting, September 16-17, 1976, Glen Arbor, Mich. 16 p.

Table 1. Confidence intervals for estimation of basal area per acre for stands from cover type 9 using Bayesian and non-Bayesian approaches.

Cover type-compartment-stand	Random plots number	mean (ft^2/ac)	variance	Sources of information for estimates[1/] P_t	P_t + R	R	$(P_t$ + R)/R	P_e + P_b	P_e+P_b+R	$(P_e$+P_b+R)/R
				95 percent confidence intervals						
9-64004-2	0			31-201				74-159		
9-75010-2	2	112	112	31-201	75-149	17-208	.388	74-159	91-136	.238
9-74054-4	2	142	112	31-201	97-175	47-238	.410	74-159	103-159	.292
9-74046-2	3	115	300	31-201	81-147	72-158	.763	74-159	92-138	.535
9-64012-1	5	66	1192	31-201	37-109	23-109	.832	74-159	59-122	.728
9-64001-4	7	146	4329	31-201	88-187	85-207	.820	74-159	92-161	.567
9-84010-1	8	129	1089	31-201	98-141	102-157	.970	74-159	104-149	.817
9-74008-1	9	133	1600	31-201	102-161	103-164	.949	74-159	102-151	.798
9-74086-3	12	111	1205	31-201	90-133	89-133	.975	74-159	93-131	.868
9-65001-2	19	122	1131	31-201	106-138	106-139	.989	74-159	106-136	.930

[1/] Definition of terms:
R = Random plots in subject stand.
P_t = Conservative empirical prior based on the distribution of all random plots (407) in cover type and bounds P_b. The mean and variance of this prior were 115 and 2055, respectively.
P_b = Type bounds prior based on an arbitrary interval. This interval was 5-256 for cover type 9.
P_e = Modified empirical prior based on all random plots (407 in 94 stands) in cover type. The 95 percent confidence interval for cover type 9 based on P_e was 74-159.

intervals were found to be very accurate. Considering cover types 9 and 8 together (the latter included 39 stands of upland hardwoods, size class 1-6 inches Dbh),

50.0 percent of the $X_{i.}$ were contained in their 50 percent confidence interval

94.0 percent of the $X_{i.}$ were contained in their 95 percent confidence interval.

A second analysis involved simulation of sample stand mean and plot distributions for various forms of priors from skewed to normal in shape.[4] These trials confirmed the accuracy suggested above and indicated considerable robustness for the modified empirical prior approach. Details of these analyses will be presented in a future article.

The results presented here for the modified empirical prior are, of course, conditioned by the somewhat arbitrary specification of the form of $f(\theta|\mu,V^2)$. The choise of a beta function was based on its flexible form, computational convenience and the fact that this function is defined over a finite range of positive values. This range was taken as from zero to the 99th percentile of the X_{ij} observations within a cover type. Other forms for $f(\theta|\mu,V^2)$ are certainly possible.

Cover Type Area Estimation

Extensive forest surveys commonly use a multiphase sampling scheme with forest type acreage estimated from a large number of aerial photo plot classifications corrected by a ground subsample. In such cases it is possible to treat the surveyed area as a set of separately inventoried survey units or districts. The area estimates for one such unit may then be improved using survey results from adjacent or nearby survey units.

Mark Hansen[5] has examined such an approach using a complete set of type maps for the five districts comprising the Chequamegon National Forest in northern Wisconsin. He used a beta density model with bounds 0 and 1 to characterize the distribution of known (assuming the type maps were accurate) proportions of a cover types over these five districts. With this distribution as a prior, the stand lists within a district were then randomly sampled with a proportional to stand acreage selection algorithm. Sampling from these lists by this procedure produced data analagous to that which would be obtained by a random sample of aerial photo plots, sans classification error. Three sampling intensities were also examined: one plot per 1000, 2500 and 5000 acres. The prior was then combined with the sample data to derive the posterior distributions.

For the four cover types examined, Table 2 describes the size of derived 95 percent Bayesian confidence intervals averaged over all three sample sizes[6] and the accuracy of the intervals. Non-Bayesian estimates or intervals were based on only the sample within a subject district.

Table 2. Performance of Bayesian versus non-Bayesian approaches to forest cover type area estimation.[1/]

Cover type	District 1	2	3	4	5
	95 percent confidence interval ratio:	Bayesian/non-Bayesian			
Upland spruce-fir	.737 (91.7)*	.706 (96.7)	.747 (100.0)	.729 (98.3)	1.054 (91.6)
Red pine	.736 (95.0)	.636 (95.0)	.716 (98.3)	.630 (100.0)	.653 (80.0)
Aspen-birch	.911 (93.3)	.847 (95.0)	.827 (100.0)	.827 (95.0)	.906 (95.0)
Northern hardwoods-hemlock	.923 (93.3)	.902 (95.0)	.903 (86.7)	.941 (91.7)	1.014 (93.3)

[1/] Results averaged over three sampling intensities.

* Percent of confidence intervals which contained the true proportion of district area in that cover type. Based on sixty trials for each district and cover type.

While these results are preliminary, at least in part because of the somewhat unrealistic prior, low sampling intensity and lack of photo classification errors, they are encouraging. In particular, thought should be given to survey unit definition and type classification which will facilitate development of precise priors. Further trials might also profit from prior bounds considerably narrower than the 0-1 values used here.

EXTENSIONS TO MULTI-RESOURCE INVENTORY

The above examples consider univariate estimation. With area estimation it would, of course,

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[4]Issos, J. N. and A. R. Ek, 1977. Bayesian estimation confidence interval analysis. Unpublished research report, Department of Forestry, University of Wisconsin, Madison. 16 p.

[5]Hansen, M. H., 1977. Bayesian methodology for forest area estimation. Unpublished research report, Department of Forestry, University of Wisconsin, Madison. 9 p. + figures, tables and appendix.

[6]In retrospect, the three sampling intensities were so low that there was little difference between them. Trials with greater sampling intensities are in progress.

be desirable to have the Bayesian estimates of proportions for various type areas sum to 1. That is not guaranteed in the trials described, but it could be using a multivariate Beta (Dirichlet distribution, see De Groot 1970) or perhaps a truncated and constrained multivariate normal density model for the prior. These priors could also be generalized to consider a wide range of resource variables. The authors are currently developing additional procedures and software for such applications.

Inherent in the derivation of priors suggested here is a fairly strict frequency interpretation. We are not advocating subjective priors for survey applications. Rather, there are many parameters in forest inventory that allow a distributional interpretation. Examples are stand volume, number of trees, tree or stand age, size class distribution, habitat indices or descriptors, forest or other type areas, user frequency, animal population numbers, etc. When these are considered as random variables, we can proceed to quantify and use the available prior information directly to improve estimates. The cost of this step should be low as it often will only involve data synthesis and some extra computation. Alternatively, we may use knowledge of gains possible from Bayesian estimation to reduce field data acquisition efforts. In typical stand examination efforts where 10-20 random or systematically located plots might normally be established, the Bayesian approach would likely provide equivalent precision with far fewer plots. In cases where data of questionable utility is requested (as is increasingly common), a good prior and related confidence intervals may suggest further sampling is unnecessary or inefficient from a cost vs utility viewpoint (Sudman 1976).

A second aspect of the type of priors suggested here is that they be unbiased or nearly so. When a prior is constructed from the same survey data for which improved estimates are desired, as in the basal area and type area examples presented here, bias, if any, should be very small. Users should expect, however, that posterior estimates will be pulled toward the prior. Initially this will bother some users, but it is simply a price paid for greater precision.

The above discussions should not rule out priors with questionable bias, such as those based on past surveys or projections of such data, but caution is needed here. Efforts should first be made to assess the likely magnitude of bias. Where present it may be handled by adjustment of distribution means and/or inflation of variances. The case noted below has much potential.

To this point it might appear that most resource inventory applications of Bayesian methodology will lie in situations where sample sizes are small. Consider, however, a survey effort repeated at ten year intervals by a sampling design based on species-size-density strata. If the strata definitions remain constant, then the mean stand characteristics within a strata may vary little over time. Of course, the stands in a strata will change over time, but then some of those what change will be considered part of another strata. Thus, though the stands and area comprising a strata may change, the mean strata characteristics may vary little. If n plots are observed at both the first and second measurements, there are nearly 2n observations available. This follows from the fact that the first survey may provide an excellent prior for the remeasurement.

There are, of course other very efficient techniques for problems involving repeated sampling of the same population (see for example the literature on sampling with partial replacement, especially Ware and Cunia (1962) and related techniques Cunia (1974)).

We hope that, with the above background and examples, inventory designers will recognize a potentially helpful tool in Bayesian methodology and attempt to integrate it into existing inventory efforts. Bayesian methodology can be a substitute or supplement to existing methodology, it does not necessarily rule out other approaches. It may lead instead to inventory designs that make more effective and direct use of prior information. Specifically, the specification of strata to facilitate the development of precise priors should have high priority.

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Time-Space and the Inventory of Ecosystems[1]

Richard J. Alvis[2]

Abstract.--Natural resources are normally distributed as time-space progressions at a relatively constant ratio. Inventories designed accordingly establish a limited range in the time-space spectrum and various natural resources are viewed as entire time-space events from the focus. Those found to conform with the focus and have field observable features sufficient to make scientific inferences serve as classification criteria for ecosystems.

There are extremely difficult, if not insolvable, problems in inventorying natural resources as ecosystems following conventional approaches. This is due to both the nature of ecosystems and traditional conceptual approaches to natural resources and their relationships. Ecosystems are composed of resources of very diverse natures, e.g., plant associations, soils, geology, climate, hydrology, and landforms, and occur in a hierarchical arrangement from large and relatively permanent entities to small and relatively emphemeral entities,i.e., at different levels of resolution. The conventional approach to ecosystems is to view the component resources as classes of established taxonomic or classification schemes, e.g., soils viewed as soil series, or soil types according to Soil Taxonomy, and plant communities as habitat types according to Daubenmeir's classification or some other scheme. This approach also tends to view relationships as direct, linear causes and effects, with little regard for hierarchical levels.

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These inventory problems are largely resolved when ecosystems and their components are regarded as time-space events and certain of their systems aspects are also considered. The time-space attributes of natural resources serve as a basis for establishment of hierarchical levels of ecosystems; for establishment of dependences, both genetic (directional) and feedback (environmental) between ecosystems and between components at different levels; for predicting future behavior of ecosystems; and finally, for identifying ecosystem components which are diagnostic for classification purposes at any level. This paper is confined to an elaboration of this last implication.

Natural resources, like all states of matter, have five primary, mutually dependent, attributes; namely, form or morphology, elements or parts, capacities or energies, time dimensions and spatial dimensions. Natural resource classification schemes have traditionally been derived from features of the former three attributes. Time dimensions refer to the interval in time during which a resource exists as a particular state, e.g., as a geologic formation, a topsoil or a leaf, and is more or less proportional to normal process rates, or dynamics while in that particular state. Spatial dimensions refer to the three dimensional sizes of a resource, and while not rigidly fixed, they do define spatial limits, e.g., trees do not exceed low hundreds of feet in height. Time-space parameters of natural resources must be considered in a very particular sense if they are to serve as the key to identification

of ecosystem components. They must be collectively considered so that a resource may only be regarded as a whole, or complete event, i.e., as a discrete entity having complete time-space unity.

Wholeness of natural resources with respect to time and space may be tested in a number of ways. One is by consideration of normal rates of change within spatial limits. Thus, a habitat type composed of several vegetative layers is regarded as having relatively little wholeness if individual plant life cycles vary appreciably between the layers, but by the same token, an individual layer may have a relatively great degree of wholeness. Wholeness may also be tested by the normal chances for spatial transformation into a different kind (class) within a given time period; or conversely, the spatial segmentation of more or less steady states along time gradients. Thus, a spatial three-dimensional soil unit (soil series) composed of layers (major horizons) with differing rates of normal change; hence, some layers, with greater chances for transformation into another kind (class) than others, would have relatively poor wholeness; whereas an individual layer would have relatively good wholeness.

When natural resources are viewed as wholes (discrete entities), they are found to be normally distributed in a definite time-space pattern. This normal pattern is along increasing time-space dimensions, within a relatively fixed time-space ratio. Thus, the size of an entity is normally a clue to its duration in time; hence, its dynamic nature and vice versa, e.g., a leaf is of smaller size, more dynamic, and more ephemeral than a tree, a tree smaller, more dynamic and more ephemeral than a climax tree association, and a climax tree association smaller and more ephemeral than a geologic formation.

Natural resources must be viewed at successively higher levels of abstraction than as discrete time-space entities if they are ever to be viewed as that very abstract entity--the ecosystem. In addition to their patterned occurrence as discrete entities, natural resources also occur as natural associations of a kind, e.g., plants occur as plant associations, as well as individuals; and concepts have been formed of such associations as entities themselves. Countless such concepts have been formed in the past to bring some degree of order or unity to a particular purpose. Not all these somewhat abstract entities or concepts at this level of abstraction are useful for ecosystem purposes, however. Only those which carry connotations of wholeness at time-space ratios approximating those of discrete entities are useful, e.g., a tree association would not be useful, but a climax tree association would. There are a number of plant ecology concepts that satisfy these requirements with respect to the vegetative aspects of ecosystems at various levels of abstraction, but a dearth of such concepts with respect to the edaphic aspects. It becomes necessary either to form new edaphic concepts or modify existing ones according to the time-space requirements, i.e., wholeness at time-space ratios approximating discrete entities.

Biotic and edaphic entities thus conceived are selected according to the commonality of their time-space dimensions. The resultant matched sets of entities are wholly contemporary, i.e., not only within a short time period, but throughout their entire existence. In addition to being wholly contemporary, the entities are distributed in nature as covariants, or spatial sets, i.e., there is a patterned geographic distribution of such entities, just as there is a patterned distribution of discrete entities. Hence, these sets of biotic and abiotic entities are wholly contemporary, are dynamic equivalents, and occur as geographic covariants. Sets such as these define the time-space dimensions or focus of an ecosystem and are criterial, or core, components to that ecosystem. They do not necessarily characterize the ecosystem sufficient to make useful interpretations but they do define, or identify, the ecosystem. The time-space focus of ecosystems serves as the sideboards for conceptualizing entities of other characterizing aspects of ecosystems, i.e., climate and hydrology. These entities are also components of ecosystems, but are considered as accessory components rather than classification criteria. Their noncriterial status is due to their lack of readily observable field features sufficient to form discrete, definitive classes.

Ecosystem components have a number of attributes in addition to those inherent to their conceptual construction, i.e., whole entities with respect to a common time-space frame and occurring as dynamic and geographic covariants. They are also mutually dependent one upon another, in such a fashion that discernible spatial class distinctions of one component implies class distinctions

of all other components; hence, a class distinction of the ecosystem. Transformations of class distinctions of one ecosystem component over time independent of similar transformations of the other components are precluded, since components have equivalent time-space dimensions. Components also occur in a steady-state, with respect to class differences, within the focus of the ecosystem, and by design, their spatial dimensions necessarily coincide with those of an ecosystem.

Core components must have attributes in addition to those necessary to establish an ecosystem focus. They must also possess field observable features sufficient to construct classes reflecting significant local differences. This requires their construction in the context of a local continuum. A prior knowledge of the most common range in the collective features of a core component throughout an inventory area is required, and, in nearly all instances, this precludes the ordering of components according to classes of an established classification scheme. Core component classes have more than one diagnostic (criterial) feature, and, in general, the more effective classes have the more numerous diagnostic features. Core components are tested or modified according to their coincidental geographic change with class changes of the other core components, and by their ease of class identification in the field. The latter test is crucial to the construction of mappable classes, since non-mappable classes are useless for inventory purposes.

Three core components invariably identified in terrestial ecosystems are: first, a dominant earth process or history, e.g., geologic, geomorphic or pedologic depending on the focus; second, a dominant kind of earth material, e.g., bedrock, soil materials, subsoil or topsoil, depending on the focus; and third, a dominant potential self-reproducing plant association, e.g., a formation, a climax tree association, or a ground union, depending on the focus. Ecosystems conceived as time-space entities were developed during the course of integrated land inventories on large areas in widely separate glaciated mountainous regions and have been subsequently successfully applied to such regions. The focus has ranged by inventory areas from either mid-pleistocene or early Wisconsin age to recent; from either two-foot or four-foot depths to 10-foot or 20-foot depths beneath the surface and from heights of either 25 feet or 40 feet, or so, to a hundred feet, or more, above the surface; and resultant map units have most commonly been low hundreds of acres in extent.

A dominant geomorphic process, relative to the surface 10 feet to 20 feet of the earth's surface, excluding the surface two feet to four feet, operative at some period within the time dimensions of the focus was used as a core component. The dominant process may also be considered the most important single genetic or historical event in the formation of the soil substrata. Classes may subdivide a process according to degrees of intensity, e.g., intensely scoured vs. weakly scoured, and all classes are inferred through stereoscopic study of aerial photographs of appropriate scale, i.e., 1:40,000 to 1:70,000. Diagnostic features include small order drainageways, their relative bifurcation ratios and degree of entrenchment; and macro and micro side slope and ridgetop shapes and gradients both vertically and horizontally. These features are studied in context of larger surrounding major landforms with a clearly defined or known common geomorphic history, and class inferences are drawn within this context. Some knowledge of the local ice age geomorphic history, construction of a local continua, and an understanding of geomorphology principles are required. Landforms developed within the focus, which are attributed primarily to structural control rather than process, are treated as abnormalities, and classified separately.

Hence, process or structural control is inferred from the study of landforms at several degrees of resolution, and classified at one degree, i.e., the focus. Landforms are not classified strictly according to their shapes nor according to catalogued landform classes. Attempts to rely solely on landform as a core component rather than a focused geomorphic process continua have invariably proven unsatisfactory. This is due, in large part, to the infinite variety of landforms encountered in a large survey area, and the attending, never-ending expansion of landform classes leading finally into an abyss of geometrics. Chaotic relationships perceived at one level of abstraction may often be rendered as an orderly relationship at a higher level of abstraction, and such is the case with landforms and geomorphic processes relative to ecosystems. Process inferences impart a degree of commonality, unity, or wholeness to core component classes that is impossible to impart from landforms alone.

Certain landforms occur more commonly than others in a process class, and they serve to typify ecosystems, but not to identify them. Mapping and classification of geomorphic classes is surprisingly easily taught, if the rapidity which trainees learn to place boundaries accurately and classify processes properly is an accurate measure. Training is conducted on a one-to-one basis using a pair of scanning stereoscopes with stratifications made from the same four dimensional reference point, i.e., the ecosystem focus.

Soil substrata is another core component contemporary with the geomorphic one. Soil taxomonic classes are not suitable as core components since they lack the necessary quality of wholeness. In one sense, this core component is no more than another aspect of the geomorphic component, i.e., kinds of soil materials are derived from and are dependent on kinds of geomorphic processes. In another sense they are both no more than two aspects of another, more abstract, multi-faceted event--an ecosystem. Diagnostic features of this component are: presence and depths to bedrock (where bedrock occurs in the focal zone), texture, gradation, consistence, permeability or bulk density, and nature of aggregates including proportional content, size distribution, shapes, and rock types present. Classes of these soil substrata properties and qualities more or less follow USDA standards and terminology. Class names follow the geologic convention, e.g., till, outwash, and are modified by salient properties, e.g., very deep permeable till, permeable till over indurated till. Soil substrata are classified in the field and a considerable knowledge of physical and chemical soil properties are required together with a working knowledge of the USDA soil classes of soil qualities and properties.

Climax tree associations serve as the third core component of these inventories. Diagnostic features are climax, subclimax, and presubclimax associations according to major (most common) species and accessory (least common) species, together with relative biomass estimates, i.e., cursory observations of collective ages, heights, and basal areas. These diagnostic features, in one sense, are inferences; however, they are a kind of inference which imparts a degree of unity sufficient to form whole classes not possible without the concept of climax. The ordering of tree species according to their structural occurrence in a community is tantamount to the ordering of landforms into geomorphic processes. In either case, the application of a scientific principle transforms a disorderly assembly of visible events or statistical data into ordered, i.e., conceptually discrete, classes. Tree species are noted in the field by relative abundance as seedlings, saplings or poles existing beneath or in the canopy, together with canopy heights and ages. The observations are made within geomorphic sideboards, i.e., according to premapped geomorphic process classes, and are made concurrent with observations of soil substrata. In addition to the concept of ecologic succession, a local knowledge of fire and cultivation histories, normal species' life expectancies, and shade tolerance of local species is required to make class determinations. Classes are named by the major climax species, e.g., beech-sugar maple association, with distinguishing modifiers of accessory species or biomass potentials as necessary, e.g., beech-sugar maple association with hemlock.

Ecosystems very effectively cluster a host of other natural resource characteristics or features. Provisions are made for noting characteristics or features geographically associated with ecosystems during the course of the inventory, and degrees of association are empirically established on a case by case basis, i.e., a particular characteristic may be very closely associated with one ecosystem class throughout the inventory area, and poorly associated with another. Qualities of wholeness distinguish between associated features and associated characteristics. Associated features are holistic, i.e., they have normal time-space ratios, but occur outside both the spatial and temporal dimensions of the ecosystem. They may be older and larger, e.g., a geologic formation; or younger and smaller, e.g., a topsoil layer or shrub layer, and are core components of other ecosystems at another focus. Associated characteristics lack wholeness with respect to time-space, and also occur outside the ecosystem focus. They may include soil taxonomic and soil engineering classes, numerous climatic values interpolated from recorded data, various micro-topographic features, many more or less recent hydrologic characteristics, and several surface soil properties and qualities. Associated features and characteristics collected during the course of an ecosystem inventory are far more numerous than the diagnostic features of core components, and although they are non-criterial for classification and mapping purposes, they are very useful for typifying and interpretative purposes. Those having

a high degree of fidelity to ecosystems enter the data bank, so to speak, alongside diagnostic features for generating predictions of future behavior of the ecosystem.

Ecosystems and components discussed to this point are considered normal with respect to time-space ratios approximating those of discrete natural entities. They are also normal with respect to more or less equal dependence on both directional (genetic) forces and feedback (environmental) forces or stresses relative to their evolution and present equilibrium, as such, ecosystem normally is homologous to pedologic zonality.

Abnormal ecosystems also occur in nature. They are ecosystems in the sense of having components with common time-space dimensions, but are abnormal with respect to time-space ratios distinctly wider or narrower than normal ratios, with a corresponding genetic or environmental influence controlling, or arresting, their normal development, and occur in a state of disequilibrium.

Ecosystems with time dimensions abnormally large relative to spatial dimensions, such as a pre-pleistocene fault scarp or a late pleistocene streambreak, occur outside normal system limits, i.e., scarp time periods larger and streambreak spatial dimensions smaller than normal focal limits. Such ecosystems are invariably rejuvenated, are structurally controlled, are in a state of edaphic disequilibrium, and are ecosystem counterparts of azonal soils. Stage of geomorphic development rather than geomorphic process serves as the core component of these kinds of ecosystems. Classes of geormorphic stage, e.g., young nature, old, reflect degrees of geologic or edaphic control and corresponding degrees of disequilibrium.

Ecosystems which have abnormally small time dimensions relative to their spatial dimensions, such as a recently formed alluvial floodplain, also occur outside normal system limits, i.e., their time dimension are smaller than the normal focal limits. These ecosystems are considered to be climatically controlled, are in a state of disequilibrium with respect to climax tree associations, and are ecosystem counterparts of intrazonal soils. Evolutionary stage of climax tree associations rather than kinds of climax tree associations ideally serve as the core component of such ecosystems. Classes of evolutionary climax stage, e.g., incipient, intermediate, mature, constructed along gradients of increasing species diversity, increasing species site requirements, and increasing species floristic development, reflect degrees of climax instability and corresponding degrees of environmental control, i.e., climatic stresses.

The concept of time-space as parameters of integrated land inventories emerged over a long period of designing and conducting first soil-hydrological inventories and later land systems inventories on glaciated mountainous regions. As the idea grew, was tested, and incorporated in the inventories, it became possible to transform land systems to ecosystems and has since become the common denominator for ecosystems. It is a theory of proven applicability to certain kinds of lands and should be applicable to all other kinds of lands as well. In the final analysis, there is nothing more practical to the inventory of ecosystems than this or some other practical and workable theory.

Potential of 3P Sampling in Wildlife and Range Management[1]

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Abstract.--Procedures used in 3P sampling, which selects sampling units with a probability proportional to predicted size and adjusts estimated values by the average measured-to-estimated ratio, are described. Possible applications in wildlife and range management inventories are discussed.

3P SAMPLING

Natural resource inventories often involve populations with great variations requiring a large number of field measurements to attain a reasonable precision of estimates. Coefficients of variation of 100% or more are not uncommon, and for a standard error equal to ±5% of the mean 19 times in 20, sample size needed for a simple random sample is calculated as:

$$n = \frac{t^2\ CV^2}{E^2}$$

where:
- n = sample size
- t = t-value, approximately 2 for a 19 in 20 chance
- CV = estimated coefficient of variation expressed as a percent
- E = standard error desired expressed as a percent of the mean

therefore: $$n = \frac{(2)^2\ (100)^2}{(5)^2}$$

$$= 1600$$

A sampling system which can greatly reduce the coefficient of variation and consequently the sample size on which measurements are required has been developed by L. R. Grosenbaugh. It facilitates the selection of samples with a probability proportional to predicted size, referred to as 3P sampling, and is incorporated into a comprehensive forest inventory program (Grosenbaugh 1974). The coefficient of variation is that of the ratios between measured and predicted sizes, often 20% or less in tree-volume studies. Estimated values are adjusted by the average measured-to-estimated ratio. For the precision specified earlier, instead of n = 1600,

$$n = \frac{(2)^2\ (20)^2}{(5)^2}$$

$$= 64$$

The procedure for using 3P sampling is:

1. If each element in the population is to be observed, estimate that number (N). If, instead, a sample of the population is to be observed, estimate that number (n).

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2. Estimate the average predicted size ($\approx\bar{x}$) of the elements or sampling units to be observed, and estimate the total as $(N)(\approx\bar{x})$ or $(n)(\approx\bar{x})$.

3. Calculate the number of 3P samples desired ($\approx n3p$) using the formula given earlier (n becomes $\approx n3p$) if each element in the population is to be observed. If a sample (n) is to be observed:

$$\approx n_{3p} = \frac{(CVr)^2}{E^2 - (CV_n)^2/n}$$

where: CV_r = estimated coefficient of variation for ratios of measured to estimated values
E = standard error desired expressed as a percent of the mean (must be set at a value somewhat greater than the error for the sample of n-observations)
CV_n = estimated coefficient of variation for the sample of n-observations

The number of 3P samples actually obtained (n3p) may vary from that desired.

4. Predict the size of the first element observed and record that value (X). If X equals or exceeds a paired random number between 1 and KZ, where KZ = $\frac{(N)(\approx\bar{x})}{\approx n_{3p}}$ or $\frac{(n)(\approx\bar{x})}{\approx n_{3p}}$, measure the element (Y). If X is less than the random number, go to the next element. Repeat this process until each element (or sampling unit) is observed.

5. For each element or sampling unit measured, calculate the ratio (r), where:

$$r = Y/X$$

6. Calculate the average ratio ($\bar{r}$) as:

$$\bar{r} = \frac{\Sigma Y/X}{n_{3P}}$$

7. The population or sample total (T) is estimated as:

$$T = (\bar{r})(\Sigma X)$$

8. The estimated standard error (E) expressed as a percent of the mean if:

(1) each element of the population was observed is:

$$E = \left(\frac{\sqrt{\dfrac{\Sigma r^2 - (\Sigma r)^2/n3p}{n3p\ (n3p-1)}}}{\bar{r}}\right)(100)$$

(2) a sample of the population was observed is:

$$E = (100)\sqrt{\left(\frac{\sqrt{\dfrac{\Sigma X^2-(\Sigma X)^2/n}{n(n-1)}}}{\bar{x}}\right)^2 + \left(\frac{\sqrt{\dfrac{\Sigma r^2-(\Sigma r)^2/n_{3P}}{n_{3P}(n_{3P}-1)}}}{\bar{r}}\right)^2}$$

In the latter formula, a covariance term is ignored as is usually done in practice (Wiant 1976).

This system is somewhat similar to two-stage or double sampling (Overton 1969) which has been widely used in range and wildlife research.

POSSIBLE APPLICATION IN WILDLIFE AND RANGE MANAGEMENT

In inventory situations where reasonable predictions can be made quickly, the 3P sampling system merits consideration. The following ideas are presented to stimulate interest in such applications.

There presently exist four areas of range and wildlife research in which the 3P system may be most applicable: (1) habitat analysis, (2) food habits, (3) censusing, and (4) size parameters of individual animals.

When evaluating cover density of vegetation, as indicated by canopy closure, stem density, browse availability, or weight of forage, where counting or clipping or weighing is time-consuming, the 3P system should greatly reduce field time required while providing adequate estimates. The coefficient of variation of Y/X-ratios can be estimated by a small, preliminary study.

Fruit, mast, and seed production can also be estimated quickly and efficiently through the use of 3P sampling. Counting individual fruits, nuts or seeds on an entire plant or even a portion of the plant is often

too time-consuming, and thus too expensive to be justified. However, 3P sampling will permit the gathering of more comprehensive data than has been previously possible.

Food habit studies can be costly, especially when it is necessary to determine amounts of each item consumed. Whether analyzing contents of crop, stomach, intestine, or scats the 3P method will permit a rapid enumeration of each food item present. This technique is especially appropriate for such research because those more important items present in large quantities will be more heavily sampled than components present in lesser quantities. Korschgen (1969) wrote regarding stomach analysis, "The foods present in greatest quantity seem to be of greatest significance to management..." Thus, whether the unit of measurement is number, volume, or weight, 3P is readily adaptable to measuring those items consumed.

Censusing wildlife populations has been, and will continue to be, an essential part of wildlife management. The 3P technique may be applicable in situations where the animal is seen or heard. For example, in aerial censusing, it is usually more important that large groups be counted than small groups. Whether it be herds of some hoofed animal or flocks of waterfowl, by estimating size of some groups and actually counting all individuals in a few groups, a larger area could be censused in a shorter time than by conventional methods. Roadside "call" counts, such as those used for mourning dove (Zenaida macroura), bobwhite quail (Colinus virginianus) and woodcock (Philohela minor), can be modified for use with the 3P system. After mentally evaluating the quality of the habitat within each segment of the census route, the biologist can estimate the number of birds which should be present and thus be calling. The typical stop and count method will be used in those segments of the census route selected as 3P samples. This use of 3P would require much more extensive knowledge of the habitat requirements of the animal involved than would a situation in which number, weight, or volume is being estimated. However, preliminary studies (with mourning doves) have shown that the method is entirely feasible.

Another area in which 3P sampling lends itself is that of ascertaining some physical parameters of individual animals. The best example of this is the determination of average weights of deer killed in a state or region. The process of weighing is time consuming, often causing much unhappiness on the part of waiting hunters. The 3P system would be helpful in this situation as the weight of each deer would be predicted but only those qualifying as 3P samples would be weighed. Experience gained by estimating weights in other studies indicate the coefficient of variation for $^{Y}/X$-ratios for those familiar with deer should be less than 20%.

These are only a few examples of situations where 3P may be applied and there are certainly numerous others. Hopefully, its application will increase precision of estimates with an overall decrease in time and expense involved.

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A Framework for Allocating Inventory Resources for Multiple-Use Planning[1]

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Abstract.--In the past, the basic approach to gathering data for multiple-use planning has been to collect large amounts of information from all possible sources. This process has several shortcomings. First, the information gathered may not be appropriate for the planning decisions under consideration. Second, the cost of data collection may be greater than necessary because not all of the information is used.

Inventories with well defined objectives are required because inventory costs are rising and more complex decisions must be made. A user-oriented approach for gathering multiple-use planning inventory data is presented. The sequence is to determine (1) the decisions to be made with the aid of inventory data, (2) the data needed to soundly base the decisions, and (3) the impact of sampling error in the data on the decisions. Sample intensities that minimize the cost of obtaining data plus the expected losses from using the data to make decisions are determined.

A cost-loss minimization framework for multiple-use planning inventory was developed and applied to a case study on a U.S. Forest Service planning unit. Results indicate that the procedure should provide useful guides for allocating sampling resources.

INTRODUCTION

In the past, the basic approach to gathering data for multiple-use planning has been to collect large amounts of information from all possible sources. This process has several shortcomings. First, the information gathered may not be appropriate for the planning decisions. Second, the cost of data collection may be greater than necessary because not all of the information is used.

Inventories with well defined objectives are necessary because inventory costs are rising and more complex decisions must be made. Dyer (1974) listed two approaches to developing a resource planning inventory system. The first starts with the decision-maker and develops an inventory system that is user oriented. The sequence for this approach is from decision-maker, to management questions, to raw data requirements, to data collection. This approach eliminates the cost of gathering data that are of no interest.

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[1]Paper presented at the Integrated Inventories of Renewable Natural Resources Workshop, Tucson, Arizona, Jan. 8-12, 1978.

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The second approach begins with the inventory design and progresses towards the decision-maker. This approach does not necessarily provide the manager with the best information for decision making because inventory specialists largely determine the types of questions which can be analyzed and it is common to produce unused data.

If the user-oriented approach to inventory design is taken, the following basic questions must be answered: (1) what decisions are to be made with the aid of inventory data?; (2) what data are needed as input to make the decisions?; and (3) what impact will error in the data have on the decisions being made? Questions (1) and (2) should be reasonably straightforward for the decision maker. The answer to question (3) is of great importance in determining inventory precision requirements because error can be reduced, but only at the cost of increased sampling intensity.

In the past, resource managers have often used rules-of-thumb to determine sampling intensity. In many cases a fixed percentage of the population was observed, but this often led to inventories that were too intensive or not intensive enough, depending on the variation in the population and the use of the data. Past experience was also used to set precision levels, but experience is of little value unless the population variance and the data use are similar to those previously experienced.

Approaches for basing sample size determination on use and cost of data have been examined by several investigators including Blythe (1945), Grundy, Healy and Rees (1956), Yates (1960), Cochran (1963), Smith (1965), Hamilton (1970), and Baron (1973). Procedures to determine optimal sample size for inventories conducted for multiple-use planning were formulated and evaluated in the study reported here. The approach began with the decision maker. Cost of collecting data plus expected loss incurred through making decisions with the data was minimized.

Hamilton (1975), listed three basic needs that must be met to use the cost-loss minimization approach. First, a cost of sampling function must be developed. Second, the distribution of possible outcomes of the inventory must be evaluated. Third, a loss function that describes the monetary losses that are expected to occur at different levels of sampling must be determined.

COST PLUS LOSS MINIMIZATION

Cost-loss minimization is a logical approach to sample size determination when decisions are made from sample results. For a given sampling method, one would expect the error of estimate--and consequently the expected loss that would result from using the estimate in decision-making--to decrease as the sample size (n) increased. However, increasing the sample size will increase the sampling cost. A logical procedure is to choose n to minimize the cost plus expected loss since this is the total cost involved in taking the sample and in making decisions from its results (Cochran 1963). Using this procedure, the calculation of n determines both the optimum size of sample and the most advantageous degree of precision.

Single Inventory, Single Decision

The method of cost-loss minimization will be developed first for the simplest case--a single inventory conducted to gather data to aid in making one decision. Throughout this section and the remainder of this paper, where applicable, the notation of Cochran (1963) will be used.

Let:

$l(z)$ = the monetary loss incurred in a decision through an error of amount z in the estimate needed to make the decision

$f(z,n)$ = the frequency distribution of z, which for a specific sampling method will depend on the sample size n.

Hence the expected loss is:

$$L(n) = \int l(z) f(z,n) dz$$

If $l(z)$ is defined as the simple squared error loss function

$$l(z) = \lambda z^2$$

where λ = a constant

then

$$L(n) = \int \lambda z^2 f(z,n)\, dz$$

$$= \lambda E(z^2)$$

where $E(z^2)$ denotes the expected value of z^2. The error, z, is defined as the difference between the estimated value and the true value, that is:

$$z = \hat{\bar{Y}} - \bar{Y}$$

where $\hat{\bar{Y}}$ = estimated value of the mean of Y
$\bar{Y}$ = the true mean of Y.

The expected loss may be written:

$$L(n) = \lambda E\ (\hat{\bar{Y}} - \bar{Y})^2$$
$$= \lambda V\ (\hat{\bar{Y}})$$

where $V(\hat{\bar{Y}})$ is the variance of the estimate of $\bar{Y}$ and the $E(\hat{\bar{Y}})$ equals $\bar{Y}$. Assuming that simple random sampling with replacement is used then

$$L(n) = \lambda S^2/n$$

where S^2 = the population variance of the sampling units.

A simple cost function is:

$$C(n) = c_0 + c_1\ n$$

where c_0 = overhead cost
c_1 = cost of observing one sampling unit
n = number of sampling units.

The cost-loss function is then:

$$C(n) + L(n) = c_0 + c_1 n + \lambda S^2/n$$

and the minimum occurs when

$$n = (\lambda S^2/c_1)^{1/2}.$$

Multiple Inventories, Multiple Decisions

In most multi-resource management situations the information from an inventory may be used in making several decisions and decisions are generally made with the aid of data from more than one inventory. The approach developed for a single inventory conducted to gather data for a single decision will be extended to the case of several independent inventories conducted to aid in making several decisions. Suppose there are q independent inventories to be conducted and m decisions to be made and that the data gathered in each of the q inventories will be used as an aid in making each of the m decisions. The q linear cost functions may be written as:

$$c_{01} + c_{11}\ n_1$$
$$c_{02} + c_{12}\ n_2$$
$$\vdots$$
$$c_{0q} + c_{1q} n_q$$

The m expected loss functions can be obtained as:

$$L_1(n_1, n_2, \ldots, n_q) = \int l_1(z_1) f_1(z_1, n_1, n_2, \ldots, n_q) dz_1$$

$$L_2(n_1, n_2, \ldots, n_q) = \int l_2(z_2) f_2(z_2, n_1, n_2, \ldots, n_q) dz_2$$

$$\vdots$$

$$L_m(n_1, n_2, \ldots, n_q) = \int l_m(z_m) f_m(z_m, n_1, n_2, \ldots, n_q) dz_m$$

Let

$$z_j = \hat{\bar{Y}}_j - \bar{Y}_j\ (j = 1, 2, \ldots, m)$$

where $\hat{\bar{Y}}_j$ represents an estimate of the jth decision variable and $\bar{Y}_j$ is the true value of the decision variable. In this case, $\hat{\bar{Y}}_j$ represents an integration and synthesis of information from the q inventories. For convenience, and because no general theory for combining information from several inventories for multiple-use decisions exists, suppose $\hat{\bar{Y}}_j$ is a linear function of the independent $\hat{\bar{y}}_i$'s from the q inventories, that is:

$$\hat{\bar{Y}}_j = k_{j1}\ \hat{\bar{y}}_1 + k_{j2}\ \hat{\bar{y}}_2 + \ldots + k_{jq}\ \hat{\bar{y}}_q$$

where k_{ji} ($i = 1, 2, \ldots, q$; $j = 1, 2, \ldots, m$) is the weight of the ith inventory value in making the jth decision and $\hat{\bar{y}}_i$ ($i = 1, 2, \ldots, q$) is the mean value from the ith inventory. (The k_{ji} weights implicitly have units such that k_{ji} times $\hat{\bar{y}}_i$ is in units of $\hat{\bar{Y}}_j$.)

The loss functions can be expressed as

$$L_j(n_1, n_2, \ldots, n_q) = \int \lambda_j\ z_j^2\ f_j\ (z_j, n_1, n_2, \ldots, n_q)\ dz_j$$
$$= \lambda_j\ E\ (z_j^2)$$
$$= \lambda_j\ V\ (\hat{\bar{Y}}_j)$$
$$= \lambda_j\ [k_{j1}^2\ V\ (\hat{\bar{y}}_1) + k_{j2}^2\ V\ (\hat{\bar{y}}_2) + \ldots + k_{jq}^2\ V\ (\hat{\bar{y}}_q)]$$

where (j = 1, 2, . . ., m). If linear cost functions and simple random sampling with replacement are assumed, the cost plus loss function to be minimized is:

$$c_{01} + c_{11}n_1 + c_{02} + c_{12}n_2 + \ldots + c_{0q} + c_{1q}n_q + \lambda_1[(k_{11}^2\ S_1^2/n_1) + (k_{12}^2\ S_2^2/n_2) + \ldots + (k_{1q}^2\ S_q^2/n_q] + \ldots + \lambda_m\ [(k_{m1}^2\ S_1^2/n_1) + (k_{m2}^2\ S_2^2/n_2) + \ldots + (k_{mq}^2\ S_q^2/n_q)].$$

The above expression may be simplified by using matrix and summation notation as follows:

$$\sum_{i=1}^{q} c_{0i} + c_{1i}\ n_i + \sum_{j=1}^{m} \lambda_j\ [\underline{k}_j'\ Q\underline{k}_j]$$

where $\underline{k}_j$ = a vector of weights used in making the jth decision

Q = a matrix where the diagonal elements are S_i^2/n_i and the off-diagonal elements are 0.

Solving for the values of the n_i's that minimize cost plus loss one obtains:

$$n_i = [(S_i^2/c_{1i})(\sum_{j=1}^{m} \lambda_j\ k_{ji}^2)]^{1/2}$$

where (i = 1, 2, . . ., q).

Multiple Attributes Observed

In the development of the cost-loss minimization framework thus far it has been assumed that only one attribute will be observed at each sampling location. For many inventories on forested land, more than one attribute is observed at each sampling location. The methods developed in the previous sections will be extended to account for multiple attribute observation in each of q inventories conducted to aid in making m decisions.

When observing more than one attribute at each sampling location, there are several alternative estimates for the variance of the attributes when determining optimal sample size. First we will consider some alternatives for determining sample size when all attributes are observed at all sampling locations. One may assume all variances equal to the largest variance of the individual attributes for that inventory. The optimal sample size can then be obtained from procedures discussed in the previous section; however, all attributes, except the attribute with largest variance, will be over sampled thus increasing the sampling cost. The expected loss will be reduced as a result of these larger sampling intensities but not by the magnitude of the increase in sampling cost.

A second method of determining an optimal sample size is to use the variance of the most important attribute in the inventory as the variance for all attributes. Methods assuming one attribute per inventory can then be used to determine the optimal sample sizes. The major shortcoming of this method is that some attributes may be over sampled while others may be under sampled.

A sample size for each attribute, rather than a sample size for each inventory, can be determined if all attributes are not observed at all sampling locations. Suppose there are q inventories and a_i (i = 1, 2, . . . q) attributes in the ith inventory then the q linear cost functions are:

$$\sum_{i=1}^{q} (c_{0i}) + \sum_{h=1}^{a_i} (c_{1ih}\ n_{ih}).$$

Suppose that information from all attributes in the q inventories is used in each of the m decisions, then the m expected loss functions can be expressed as:

$$L_1(n_{11}, n_{12}, \ldots, n_{qa_q}) = \int l_1(z_1)\ f_1(z_1, n_{11}, n_{12}, \ldots, n_{qa_q})dz_1$$

$$L_2(n_{11}, n_{12}, \ldots, n_{qa_q}) = \int l_2(z_2)\ f_2(z_2, n_{11}, n_{12}, \ldots, n_{qa_q})dz_2$$

$$\vdots$$

$$L_m(n_{11}, n_{12}, \ldots, n_{qa_q}) = \int l_m(z_m)\ f_m(z_m, n_{11}, n_{12}, \ldots, n_{qa_q})dz_m$$

As before:

$$z_j = \hat{\hat{Y}}_j - \bar{Y}_j$$

Suppose $\hat{\hat{Y}}_j$ is a linear function of the $\hat{\hat{y}}$ values of the attributes, then:

$$\hat{\hat{Y}}_j = \underline{k}_{j1}'\ \hat{\hat{\underline{y}}}_1 + \underline{k}_{j2}'\ \hat{\hat{\underline{y}}}_2 + \ldots + k_{jq}'\ \hat{\hat{\underline{y}}}_q$$

where $\underline{k}_{ji}$ = a vector, a_i in length, of weights of the ith inventory in making the jth decision ($i = 1, 2, \ldots, q$; $j = 1, 2, \ldots, m$)

a_i = the number of attributes observed in the ith inventory.

Thus the squared error loss function for the jth decision is:

$$= \lambda_j E(z_j^2)$$

$$= \lambda_j V(\hat{\bar{Y}}_j)$$

$$= \lambda_j [\underline{k}_{j1}' \, V(\hat{\bar{\underline{y}}}_1) \, \underline{k}_{j1} + \underline{k}_{j2}' \, V(\hat{\bar{\underline{y}}}_2) \, \underline{k}_{j2} + \ldots + \underline{k}_{jq}' \, V(\hat{\bar{\underline{y}}}_q) \, \underline{k}_{jq}]$$

where $V(\hat{\bar{Y}}_i)$, ($i = 1, 2, \ldots, q$), is a variance-covariance matrix for the ith inventory.

If simple random sampling with replacement is assumed $V(\hat{\bar{y}}_i)$ is a matrix, Q_i, with diagonal elements:

$$S_{ih}^2/n_{ih} \qquad (h = 1, 2, \ldots, a_i)$$

where S_{ih}^2 is the variance of the hth attribute in the ith inventory. The off-diagonal elements are:

$$S_{ih(il)} \, [2/(n_{ih} + n_{il})]$$
$$(h, l = 1, 2, \ldots, a_i;\ h \neq l)$$

and $S_{ih(il)}$ is the covariance between the hth and the lth attributes of the ith inventory.

Under the stated assumptions and definitions the cost plus loss function to be minimized is:

$$\sum_{i=1}^{q} (c_{0i} + \sum_{h=1}^{a_i} c_{1ih} \, n_{ih}) + \sum_{j=1}^{m} (\lambda_j \sum_{i=1}^{q} \underline{k}_{ji}' \, Q_i \, \underline{k}_{ji}).$$

Sets of equations, and unknowns, will be formed by taking the first partial derivative with respect to each n_{ih} and setting the partial equal to zero. Each set will contain equal numbers of equations and unknowns but no solution can be obtained analytically for the n_{ih} values. However, it may be possible to obtain an approximate solution by using iterative procedures for solving a system of non-linear equations.

An approximate solution for the n_{ih} values can be obtained if the covariances between attributes are assumed to be zero. The resulting equations are the same as those developed for q inventories with one attribute to make m decisions, except that there is a larger number of equations, namely:

$$n_{ih} = [(S_{ih}^2/c_{1ih}) \, (\sum_{j=1}^{m} \lambda_j \, k_{jih}^2)]^{1/2}$$

where ($i = 1, 2, \ldots, q$) and ($h = 1, 2, \ldots, a_i$).

In practice all attributes are usually observed at all sampling locations. This procedure is logical since the overhead cost and cost of initially establishing a sampling location are generally very large relative to the cost of observing a given attribute once at the location. If all attributes are observed at each sampling location, then all n_{ih}'s are equal (to n_i). If the effects of the variance of each attribute on the sample intensity are wanted for an inventory in which each attribute is observed at each sampling location, the total cost function to be minimized is:

$$\sum_{i=1}^{q} (c_{0i} + c_{1i} n_i) + \sum_{j=1}^{m} (\lambda_j \sum_{i=1}^{q} \underline{k}_{ji}' \, Q_i \, \underline{k}_{ji})$$

where Q_i is a variance-covariance matrix with diagonal elements

$$S_{ih}^2/n_i \qquad (h = 1, 2, \ldots, a_i)$$

and the off-diagonal elements equal zero.

Taking the q partial derivatives with respect to the n_i's ($i = 1, 2, \ldots, q$) and setting them equal to zero, the values of the n_i's that minimize the cost plus loss functions are:

$$n_i = [(\sum_{j=1}^{m} \lambda_j \sum_{i=1}^{q} \sum_{h=1}^{a_i} k_{jih}^2 S_{ih}^2)/c_{1i}]^{1/2}$$

where ($i = 1, 2, \ldots, q$).

Decisions Made More Than One Time

When management plans are made for large land areas it may be necessary to make any given decision many times. If these decisions are independent, then the expected loss is simply the sum of the expected losses for each time the decision is made. For example, in the case of multiple inventories and multiple decisions, where all assumptions and definitions remain as previously stated, and where T_j represents the number of times the jth decision is made, the total cost-loss function

to be minimized is:

$$\sum_{i=1}^{q} \left(c_{0i} + \sum_{h=1}^{a_i} c_{1ih} n_{ih}\right) + \sum_{j=1}^{m} \left(T_j \lambda_j \sum_{i=1}^{q} \underline{k}'_{ji} Q_i \underline{k}_{ji}\right)$$

APPLYING THE COST-LOSS MINIMIZATION PROCEDURE: A CASE STUDY

The user-oriented approach to developing a sampling design and the minimization of cost-loss functions to determine sampling intensity were applied to a multiple-use planning situation. To apply the cost-loss minimization approach, several assumptions were made. First, linear cost functions were used as a first approximation. Second, squared error symmetric loss functions were selected in the absence of specific loss functions for the various multiple-use decisions. Third, simple random sampling was employed.

The Forest Service, U.S. Department of Agriculture is using unit planning (U.S. Department of Agriculture 1970, 1973) as the technique to manage the National Forests for multiple use purposes. A unit is a geographical management area that is usually defined as a watershed or an isolated ownership. A unit plan "... is a total management plan for all the social, economic, natural resource, and other environmental situations found within a unit." (U.S. Department of Agriculture 1973, p. 2). An interdisciplinary planning team develops alternative management strategies from which the 10-year unit plan evolves.

The case study was conducted on the 71,188-acre High Knob Unit of the Jefferson National Forest. The Unit is located in the Appalachian Mountains of southwestern Virginia. (See Burkhart, et al. 1976 for additional information about unit planning and the High Knob Unit).

The three major steps in this evaluation were: 1) to list the decisions necessary for unit planning; 2) to determine the input information needed to make these decisions; and 3) to determine the sampling intensity that will minimize the cost of obtaining data plus expected loss involved in using the data to make decisions.

Decisions and Inventory Requirements for a Unit Plan

The resource management decisions in a unit plan can be grouped into three production categories--timber, wildlife, and recreation. All remaining functional areas in the Supervisor's Office act as support units for these three production areas. Inventories from both production and support function groups are, however, necessary to obtain the required information to make unit planning decisions.

The decisions made for a unit plan can be placed into two groups. First, are decisions requiring no inventory information, such as policy decisions. Second, are decisions that require inventory information; it is these latter decisions that we were concerned with in this study.

Listed below are examples of decisions that rely on inventory data and the inventory information that is required to more soundly base the decision.

1. What timber stands within the unit have timber products that could be scheduled for harvest?
   - stand age
   - forest type
   - stand condition class
   - site index
   - operability
2. Are there negative impacts that dictate the type of timber harvest?
   - distance zones, sensitivity levels
3. Are there soil restrictions that dictate the type of timber harvest?
   - soil modifiers
4. What wildlife species are to be featured on the unit?
   - stand age
   - forest type
5. Which streams are to be stocked with trout?
   - trout reproduction
6. Are there areas where public use should be restricted?
   - soils modifiers

The data needed to make the above decisions are obtained from inventories by four functional staffs. As part of the timber inventory, stand age, stand condition class, forest type, site index, and operability are determined. The wildlife inventory identifies

trout reproduction. The soil modifiers are inventoried by the soils specialist. The landscape architect inventories the distance zones and sensitivity levels.

Determination of Sampling Intensity

As stated earlier the sampling intensity was determined as a function of the value of the information observed rather than by some rule-of-thumb. The minimization of cost-loss functions was used in this determination. In the High Knob Unit example four inventories, of which one has five attributes, must be conducted to collect information to make six decisions. To determine sample size with the cost-loss approach five types of information were developed: (1) variance-covariance estimates; (2) cost figures; (3) λ determinations; (4) k vector values; and (5) T values. The staff of the Jefferson National Forest, as the decision-makers, were consulted in obtaining this information.

Obtaining Variance Estimates

For an inventory with only one attribute, only a single estimate of the variance is needed, but for an inventory with more than one attribute the variance of the attributes and the covariances between attributes must be estimated. Variance and covariance estimates were obtained from existing information on the High Knob Planning Unit.

Cost of Inventories

The best cost information available was obtained from the records of the Jefferson National Forest. The cost for each inventory was divided into overhead cost and cost per sampling unit.

Determination of λ Values

A λ value was determined for each decision. The decision-makers were consulted as to the monetary loss that would be incurred from making decisions with information containing varying amounts of sampling error (z). When more than one attribute was used to make a decision, a unit of measure for z had to be determined that related all the attributes. For example, the decision of which wildlife species is to be featured in an area uses stand age and forest type. The unit of measure of z was determined to be habitat. A linear regression line was fitted using z^2 as the independent variable and loss as the dependent variable. The line was forced through the origin since data with no error would enable decision making with no loss. The slope of the regression for each decision was used as an estimate for λ.

Development of k Vectors

The decision-makers of the Jefferson National Forest were questioned as to the weight they placed on information needed to make each decision. Four vectors for each of the six decisions were developed. Each vector represented an inventory. For each attribute not needed to make a particular decision, a zero was entered in the appropriate vector element. For the attributes contributing to making a decision, the decision-maker placed a number representing the weight of that attribute with respect to the other attributes contributing to making the decision.

For example, to make the decision what stands to schedule for possible harvest the five attributes from the timber inventory are needed. The vectors for the remaining three inventories are vectors of zeros. The decision-maker considered stand condition class and site index twice as important and operability three times as important as stand age and forest type. Therefore, stand age and forest type were given values of one, stand condition class and site index were given values of two, and operability was assigned a value of three.

If only one attribute per inventory was assumed then only one vector would be developed for each decision. Each element in the vector would represent the weight of importance of that inventoried item in making the decision.

Determination of T Values

A T value for a decision is the number of independent times the decision is made on the unit. Appropriate T values were determined for each decision by estimating the number of times the decision would be made for the 10-year High Knob Unit Plan.

Minimization

Several approaches can be taken to minimizing the cost-loss functions. These minimizations procedures vary according to the assumptions made concerning the variance-covariance matrix and whether or not all attributes of an inventory are observed at each sampling location.

Four minimizations, in which covariances were assumed to be zero, were accomplished for the High Knob Planning Unit case study. The four approaches taken were: (1) to use

the largest variance of the attributes observed as the inventory variance and assume that all attributes will be observed at all sampling locations, (2) to assume all variances of an inventory to be equal to the variance of the most important attribute and that all attributes will be observed at each sampling location, (3) to assume that each attribute will be observed at each sampling location and use the variance of each attribute in the calculation of sampling intensity, and (4) to calculate a separate sample size for each attribute.

Changes in the cost-loss values between the four minimizations were relatively small. These small changes were partially a result of a large fixed cost component. For the cost and variance relationships in this case study, any of the four methods should be useful for establishing a guide to sampling intensities.

A fifth approach to determining sampling intensity involved computing the sample size for each attribute instead of for each inventory and using estimated covariance values between attributes of the same inventory. However, the resultant set of equations could not be solved analytically, and an attempted numerical solution involving the Newton-Raphson procedure failed.

Discussion

Determining sampling intensity for multi-resource inventories based on the value of the information appears to be a feasible approach. However, difficulties do arise in practice. One of the most prominent is the difficulty of estimating monetary losses from making decisions based on information containing various amounts of sampling error. In this study, a squared error loss function was assumed appropriate. Loss functions may be of some other functional form, depending on the decisions involved. Other areas for potential improvement include developing cost-of-sampling functions and deriving models for combining data from various sources to aid in making a single decision.

In many instances it will not be possible to develop monetary estimates of the value of information from an inventory. The decision to undertake the inventory and the specification of precision must then be a matter of judgment by those who require the information and those concerned with the allocation of resources. However, even when optimal precision levels cannot be quantitatively determined, careful thought should be given to the costs of data acquisition and the probable consequences of varying amounts of sampling error in the data. The process of specifying decisions that need to be made, data that are needed to aid in making these decisions, and losses that are expected from making decisions with sample data should guide managers toward more efficient allocation of sampling resources.

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Mertrication: Its Application in Forest Mensuration[1]

David W. Robinson[2]

Abstract.--While the term metrication still evokes negative responses from many practioners in the profession, it appears to be coming anyway. This paper gives a summary of current status in metric changeover and points out how really minimal the field problems are in applying metric measurements in the forest.

Depending on who one addresses, the mention of metrication evokes a wide range of response. The managing director of the Cowboy Hall of Fame (a museum and gallery dedicated to recording the heritage of the Old West) has been actively arguing against the metrication of America on the grounds that the West was not won using metric jargon (Krakel 1977). On the other hand much has been said about the role of metrication in the Nation's ability to compete in the foreign market. Some time ago in response to a proposed manuscript taking the advocates position of "let's get on with it" the following response was received from the Editor of the Journal of Forestry.

> "The Journal believes that change toward metrication is imminent, but it would like to restrict itself to examining what change is likely to involve and to avoid partisan positions that change is good or bad."[3]

While the author does not agree with the general philosophy of no controversy on such matters, the objective of this paper is to report on metrication progress in forestry and to relate some actual experiences with metric measurements in various forest situations. It's my hope that through examination of such experiences, apprehension towards the impending metric changeover in forestry will be reduced.

A brief historical review might be in order. The Metric Conversion Act was signed in December 1975. The steps leading up to the Act's passage were initiated in 1965 by the Federation of British Industry. Six years later the U.S. Department of Commerce published a series of recommendations encouraging the changeover in the U.S. The 1975 Act incorporates most of the Commerce Department's recommendations which included a seventeen member coordinating board to promote voluntary change.

The Society of American Foresters and the National Forest Products Association were active on the metric scene prior to 1970. The softwood lumber industry has already prepared a draft proposal on metric lumber sizes. The Society of American Foresters established a Metrication Committee which has systematically been creating metric awareness through Journal articles. Presently, the Committee has in production a slide tape show that will soon be made available to all units of the Society. The program is designed to further create awareness and to introduce the basic metric concepts.

The Canadian forestry community has made much more progress towards changeover than has the United States community. The provincial and federal governments joined the industry some time ago in a decision to have orderly progress towards metric changeover by mid-1979. Most of the size standardization has been completed and they are presently going through an intensive industry-wide training program. There is every confidence that Canada will have completed the metric forestry changeover by the mid-1979 goal (Sector Committee 8.1-8.2, 1977).

There are many problems yet to be resolved in the United States regarding standards. As an example I've been asked by the SAF Metrication Committee to poll this conference regarding preferences for the standardization of the dbh measurement point. (See materials included in the registration packet.)

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[1]Paper presented at the Integrated Inventories of Renewable Natural Resources Workshop, Tucson, Arizona, January 8-12, 1978.

[2]The author is Professor of Forestry, Department of Forestry, Oklahoma State University, Stillwater, OK 74074.

[3]Sand, N.H., Editor, Journal of Forestry. Personal communication, January 1976.

As Bruce (1974) so ably pointed out, most of us move very slowly against changes in tradition. Our reluctance to give up the cord, board foot and Doyle log rule is indicative of this. What I hear from practicing professional foresters is much the same that I haer from my wife and friends around the bridge table. "Why change? It's confusing! I'll never learn it! It doesn't make sense! What will we do about land measurements? What about the cost to retool? It will create a dual system!" etc. I must confess that I've experienced most of these reactions myself.

My introduction to the practical use of the metric system in forestry came as a result of spending a summer in Brazil with forty students in our regular summer camp. Since we were equipped entirely with English measuring equipment, we were forced to make soft conversions of all work in order to express our results in terms that the host company could use. This was an excellent experience because it forced us to become familiar with the metric terms as well as providing experience in judging relative values between English and metric quantities. A single four week exposure to metric thinking broke down all the apprehension barriers that existed. Students and faculty alike, gained considerable confidence in using the metric system. This experience is similar to that of anyone having had an international experience where metric measurement was a standard practice. While some suggest that learning the metric system is akin to learning a new language, I would suggest that it is not nearly so complex as learning Portuguese.

In response to positive student feedback from the Brazil experience and out of a sense of responsibility to the future, we secured financial support and added the equipment necessary to have the direct measuring metric capability. By spending less than $100 per crew (1975) we were able to make the conversion. Depending upon the cruising objective the cost for converting to the metric capability is not nearly as formidable as one might suspect. Equipment supply firms have done an excellent job of making the right tools available. In most cases by simply buying replacement items with the metric/English capability, an equipment cache can be converted in a short period of time.

Following the Brazil camp we've had two camps in western Montana and one in southeastern Oklahoma. We have as a general rule, cruised, scaled, built volume tables, built stand and stock tables, made growth projections, etc., using English units for one species group and metric units for another. Once the data is summarized and expanded to a per unit basis, soft conversions are made in both directions. Other than increasing the workload, there have been surprisingly few problems encountered. Most of the students come to feel very comfortable with the metric units. They pick up the jargon readily, use it correctly and even express a preference for it by the end of the four weeks.

During the last three summers we've cruised over 1200 ha of American forestland, developed local volume tables for Douglas-fir, ponderosa pine, and shortleaf pine using direct metric measurements and standing tree dendrometry on 150-200 trees in each species group. In selecting basal area factors we've found that the metric BAF's of 2.5 m^2/ha, 5 m^2/ha, produce approximately equivalent estimates to the English BAF's of 10 ft^2/a and 20 ft^2/a when sample unit frequencies are the same.

In some respects we've come to believe that from a forest management standpoint, the hectare may be a more useful area unit than the acre because of its larger size. While the initial reaction might be one of concern for dualism, many forest management systems use dual accounting systems already.

In discussions I've had with foresters about the impending changeover, concern is expressed that there is not much we can do about changing in the woods until the product standards are established. It's true that we've been slow to free the woods from product-oriented units and while the cord and board foot still seem entrenched in some areas, we've generally started the move away from such hang-ups. Pounds and cubic feet, while related to product yields, are not dependent upon the manufacturing process itself. The shift to mass and cubic volume is making the step to metric much easier.

Metric measurements are simple, consistent and functional for the task of measuring the forest. Our experience with metric is but a sample of what is to come. We have overcome our fear of change through determined use, and in fact have come to prefer it. You're apt to have the same experience. "Try it. You'll like it!"

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Panel VII — Data Processing Systems: Moderator's Comments[1]

John W. Moser, Jr.[2]

"Everything requires time. It is the one only true universal condition. All work takes place in time and uses up time. Yet most people take for granted this unique, irreplaceable, and necessary resource. Nothing else, perhaps, distinguishes effective executives as much as their tender loving care of time." The foregoing quote by Peter Drucker may equally apply to effective inventory analysts, biometricians or resource managers. During the past decade, modern computational systems have been the most significant element for increasing our productivity during work time. Thus, in an integrated inventories workshop, it is appropriate to include presentations emphasizing computational methodology that can contribute to the effective allocation of time in managing the Nation's natural resources.

The workshop theme focuses on the concept of integration. To most of us, this implies that our inventory systems should not be oriented to a single resource but we should strive to collect descriptive and interrelated attribute data for many resources. While the concept is simple and straightforward, we are finding many pitfalls and obstacles in implementing design, data collection, and analytical methodology. I did not intentionally leave computing out of the problem areas as often computing is taken for granted. Managers have been told that computers can "crunch" all data and provide all the current decision-making information if we can just get the data collected. Yes, it is true that (1) computers have grown smaller in size yet have increased capabilities and faster speeds, (2) systems analysts have become more independent and (3) software vendors have developed more convincing sales pitches. However, it does not follow that adequate data processing will result. To avoid additional hazards, the implementation of successful integrated inventories requires integration of the planning effort starting with the objectives and design specifications and continuing through the computational phases.

It is my opinion that the computational aspect of implementing inventories is, perhaps, a less difficult and costly phase. Rapid developments are occurring in both the hardware and the software areas of the computing industry. Utilization of these new products often requires the programming of solutions to difficult design and data collection problems. I am not implying that data processing will necessarily follow smoothly as I've spent too many hours in the computer center debugging pseudo-operational systems. I do wish to imply that once the analytical details are apparent, readily available, inexpensive computing power can be directed toward the completion of the inventory project.

While it is obvious that computational problems abound, solutions and programs are emerging. The presentations by members of this panel will focus upon current data processing technology.

First attention will be directed toward data integrity. Edit procedures are extremely important features of any processing system to assure reliable results from subsequent analyses. The presentation will address the use of graphic display modes for checking inconsistencies in spatially distributed data. The second paper will focus upon programs for use with small computers. With the current emphasis on minicomputers and micro-processors, this area will undoubtedly increase in importance for satisfying many computing needs. In the third paper, attention will be given to the area of processing systems for small ownerships. Descriptions and assessments will be provided for a wide range of operational systems. Following this excellent coverage of present systems, the fourth paper will describe a program that illustrates how many of the present systems could be adapted for

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[1] Presented at the Integrated Inventories of Renewable Natural Resources Workshop, Tucson, Arizona, January 8-12, 1978.

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providing integrated inventory summaries. Through modification of a timber inventory program, summaries are provided for wildlife food and habitat as well as timber.

The fifth paper will be directed towards an established, generalized inventory system that provides the user with a large degree of flexibility in meeting a variety of inventory processing requirements. While originally developed in the mid 60's, the system does contain a rudimentary language for user communication. In future systems, a conversational communications mode will become more prevalent. This feature will ultimately lead to ease of program application and use.

The system presented in the sixth paper grew out of the cooperative efforts of a diverse scientific staff to utilize a resource data base for evaluating treatment opportunities and for anticipating future forest resource conditions. It typifies the integrated efforts that will become commonplace as team efforts are directed toward resource management problems.

The final paper in the panel will discuss the integration of data between various agencies. This paper begins to focus our attention towards the new horizons of the computer industry - the area of data management. The conventional data processing systems are reaching towards maturity and serving their clientele extremely well; however, the interest in management information systems is increasing tremendously. Further pursuit of this topic will come in the next panel.

In looking at current data processing technology, I think mention should be made of another area that is receiving considerable attention. This is in the area of distributed processing. Three factors seem to highlight the trend towards this concept. They are (1) increased numbers of users going on line, (2) the growth of intelligent terminals and (3) the number of systems supporting data communications networks. Characteristics of the distributed processing systems include (1) dissemination of processing power through the system, (2) unloading of the host computer, (3) reduction of communications cost and (4) functions isolated from the mainstream of applications are performed locally. Figure 1 is a diagrammatic representation of a distributed processing system that is currently being developed at Purdue University to provide processing and communications between the county Extension offices and the main campus. The system, known as Fast Agricultural Communications Terminal System will provide stand-alone processing and local data bases in each county office while routing more complex tasks to either the front end processor or the host computer on the main campus. The system's primary function is to efficiently provide data and management information about agriculture and its allied areas. Distributed processing systems are currently in their infancy. Many of the topics presented in this panel lend themselves to such processing. Thus, perhaps, many of us will be utilizing distributed processing systems to manage the forest resources over the coming decade.

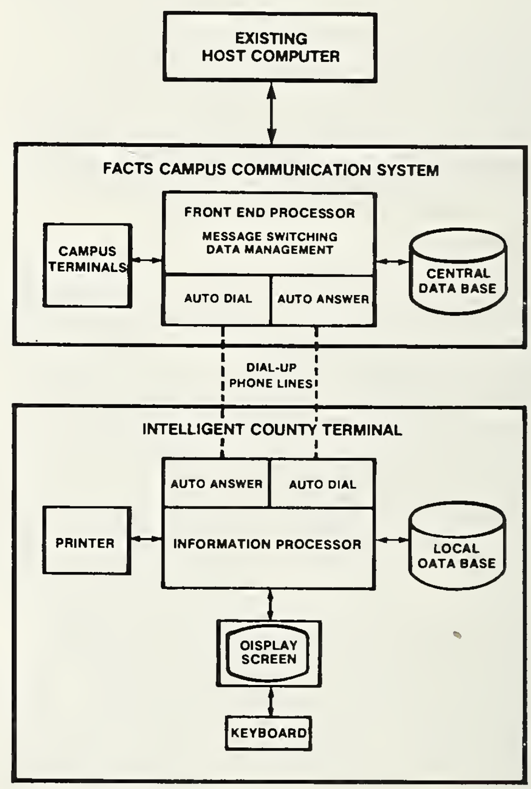

Figure 1. -- Diagrammatic representation of a distributed processing system under development at Purdue University.

An Automatic Data Processing System for Multiple Resource Inventories[1]

Dieter R. Pelz[2]

Abstract.--A forest inventory data processing system for multiple resource inventories is described. The system provides the user with information on timber, wildlife food, and wildlife habitat. Timber information includes basal area and volume by diameter class and species and growth predictions. Wildlife food and habitat information includes acorn and nut production, shrub biomass and the number of den trees in the forest.

INTRODUCTION

Forest inventory data processing systems are successfully being used to summarize data collected in timber inventories. The use of these systems relieves the field foresters from time consuming and tedious calculations and summarizations of inventory data.

Several programs have been developed for processing timber inventory information. The Forest Inventory System (FINSYS) has been developed by the U. S. Forest Service (Frayer et. al. 1968) for use under a variety of forest conditions. It is very flexible and allows summarizing timber data efficiently. Several other systems have been developed for regional or state wide use. Mawson and Gornowski (1968) developed SURVEY, a system for processing timber inventory data from small to medium forest holdings in Massachusetts, and Myers et.al. (1973) described a system for processing point sampling inventories on forest lands in Vermont. Moser (1970, 1972) developed the Purdue Forest Data Processing Program to summarize timber inventories on forest land in Indiana. Ek et. al. (1973) adapted this program to the forest conditions in Wisconsin.

These inventory data processing systems provide the user with a rapid summary of timber data. A number of different sampling designs may be used with most systems, plots of varying size or points with different basal area factors can be processed. Statistical summaries are provided by several systems. All programs compile stand and stock tables and calculate timber volumes.

Nontimber forest data can be processed by most systems only after major program revisions if at all. The Illinois Forest Inventory Data Processing System was developed to process multiple resource inventory data. An earlier version of the Illinois system is described by Pelz and Thom (1977).

The system was developed in cooperation with the Illinois Department of Conservation-Division of Forestry for processing data from forest inventories of private woodlands and state forests in Illinois. The timber summary portion of the system is modeled in part after the Indiana system developed by Moser (1970, 1972). In the following, the main aspects of the Illinois system are described in some detail.

THE ILLINOIS FOREST DATA PROCESSING SYSTEM

The Illinois Forest Inventory Data Processing System can be used to process data from timber surveys, wildlife food and habitat surveys, ecological surveys, or multiple forest use surveys. The system is user oriented and

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[1]Paper presented at the Integrated Inventories of Renewable Natural Resources Workshop, sponsored by the Society of American Foresters' Working Group and the University of Arizona, School of Natural Resources, January 8-12, 1978, Tuscon, Arizona.

[2]Assistant Professor of Forest Biometrics, University of Illinois, Urbana, Illinois.

requires no knowledge of automatic data processing or computers. Access to the system is simple as one common input form is used for all options. The computer program is written in Fortran IV; the system is operable on an IBM 360/75 and CDC CYBER 175.

The program accepts data from 100 percent inventories, fixed area plot sampling, and point sampling. Data may be recorded in the English or metric measurement systems; the output is generated in the appropriate measurement system.

Individual tree tallies are being used. For each tree the species is recorded, and the diameter, height, tree classes, and growth during the last ten years if appropriate. A total of 55 different tree species is included; the species abbreviation is a three letter combination. In addition 10 shrub species are included for the wildlife food and habitat inventory.

During the inventory each tree is assigned one to three tree classes indicating tree quality, wildlife habitat information and whether the tree is sawtimber or pulpwood.

Tree class abbreviations and their definitions follow:

1 - Good growing stock. Dominant or co-dominant crown position, few defects.
2 - Medium growing stock. Dominant, co-dominant, or intermediate crown position, more defects than class 1.
3 - Poor growing stock. Any crown position, more defects than previous classes, but less than 50 percent.
4 - Cull. Defects higher than 50 percent.
5 - Den tree with lower cavities (cavities in the lower 3/4 of the stem).
6 - Den tree with upper cavities (cavities in the upper 1/4 of the stem).
7 - Dead standing tree.
8 - Squirrel leaf nest.
9 - Special class (defined by user).
10 - Special class (defined by user).
P - Pulpwood tree

Up to three of these classes may be recorded for one tree, e.g. one tree may have the code 2 6 8 which indicates that the tree is medium growing stock, with upper cavities (the tree is or could be a den tree), and that a squirrel leaf nest is present.

Timber Inventory

Classes 1 to 4 are timber classes. For these classes the basal area per acre or hectare is printed in 2 inch (or 5 cm) diameter classes from a minimum of 2 inches (5 cm) to 40 inches (100 cm) diameter. The volume is listed for 2 inch (5 cm) classes from a minimum diameter of 10 inches (25 cm) to a maximum of 40 inches (100 cm). Volume and basal area by species are also shown as histograms (Figure 1). Volume units may be expressed in any desired unit. International 1/4" board foot volume is calculated with a volume table, and for cubic foot volume or cubic meter volume equations are being used. Standard cull deductions are applied to all calculated volumes: tree class 1 is reduced by 5 percent, tree class 2 by 10 percent and tree class 3 by 25 percent; classes 4 to 10 have zero volume by definition.

Sampling designs that can be processed by the system are:

(1) systematic sampling - no statistical summary is provided.
(2) simple random sampling - statistical summary is provided for basal area, volume and number of trees. For each of these variables the mean, variance, standard error, and 95 percent confidence interval are calculated to allow an estimation of the precision of the results.
(3) stratified random sampling - statistical summary is provided for up to 9 strata separately and the total stand.

The growth of the forest can be determined by taking increment cores from selected trees in the stand. The program provides a ten-year stand and stock table projection, and calculates the average annual basal area and volume increments (Figure 2).

Wildlife Food Inventory

The system provides information on some wildlife food production of the forest. Acorn and nut production is predicted from tree data; shrubs that are being used for browsing can be inventoried in addition.

Acorns and nuts are an important part of wildlife forage, they are consumed by many different animals such as deer, squirrel, ducks, turkey, bear, and others. Thus, information on the availability of acorns and nuts is important for making wildlife management decisions. For all oak species the expected acorn production, and for all nut producing species such as walnut, hickory, and pecan, the expected nut production in pounds per acre or hectare are estimated. Acorn and nut production tables are stored within the program giving the acorn and nut production per square

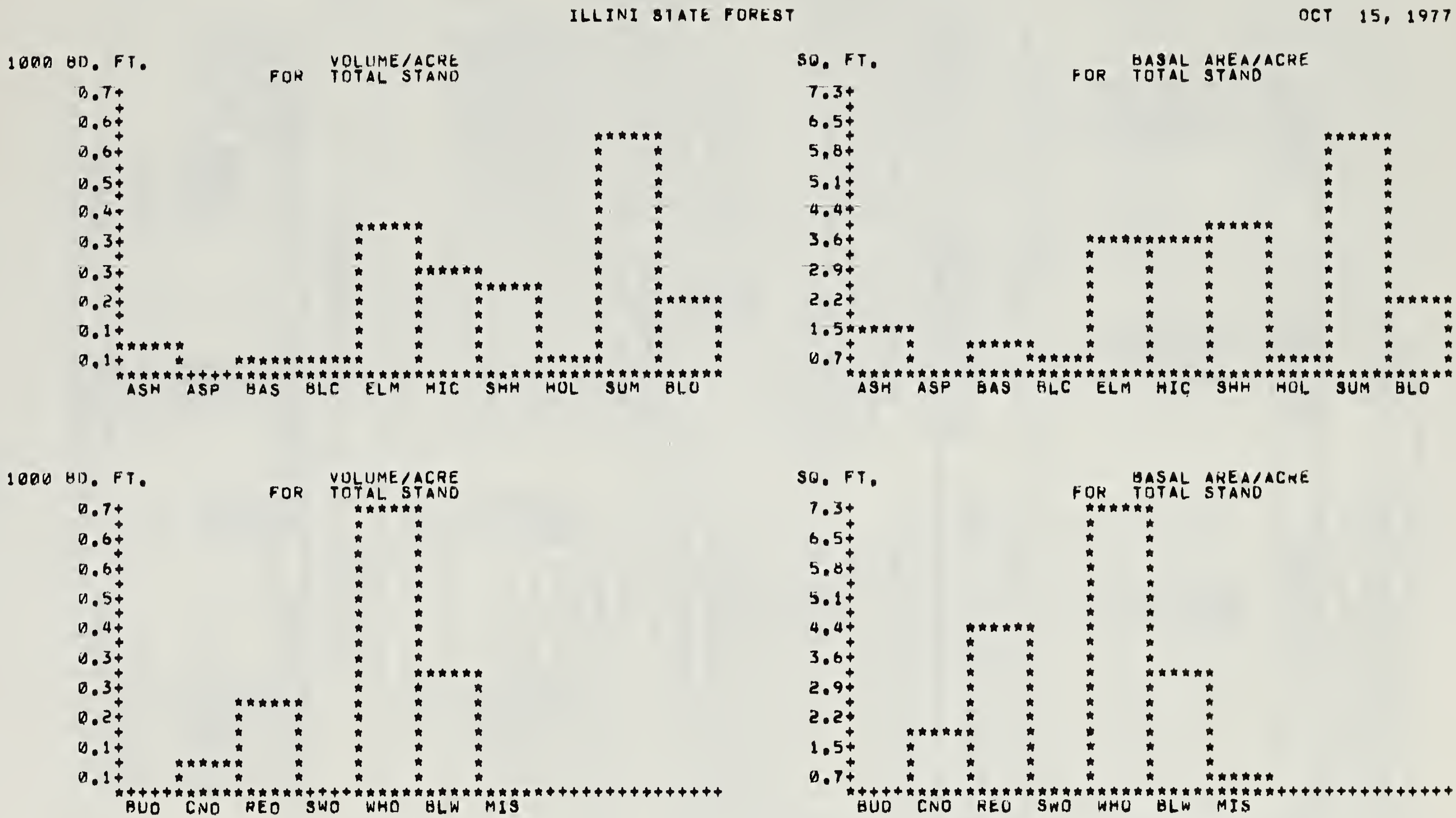

Figure 1.--Volume and basal area output

Figure 2.--Growth output

TEN YEAR PREDICTED STAND AND STOCK TABLE FOR
"GOOD GROWING STOCK"
ILLINI STATE FOREST

DIAMETER CLASS	NO. TREES PER ACRE	BASAL AREA PER ACRE	VOLUME PER ACRE
10	2.6	1.42	99.5
12	9.0	7.06	498.1
14	3.8	4.02	390.1
16	3.1	4.32	487.8
18	1.9	3.38	426.2
20	1.1	2.29	281.9
22	0.7	1.83	238.6
24	0.4	1.18	152.8
26	0.2	0.55	84.5
28	0.1	0.25	41.0
T O T A L S	22.7	26.31	2700.7

GROWTH PREDICTION IS BASED ON 21 OBSERVATIONS

AVERAGE ANNUAL GROWTH PER ACRE INT.1/4" BD.FT. 126.6
SQ. FT.BASAL AREA 0.63

foot basal area by diameter classes. The production data used are based on studies reported by Byrd and Holbrook (1974), Shaw (1974) and Goodrum et. al. (1971). These production tables can easily be updated or expanded to adapt the program to local conditions. The acorn and nut production is estimated by the program automatically; other wildlife food information can be processed if requested during input. An example for the acorn and nut production table is shown in Figure 3.

The program calculates shrub biomass from basal stem diameters for the shrub species identified. The availability of browsing material for wildlife can then be related to shrub biomass. Basal stem diameter and biomass relationships are modeled after the study described by Brown (1976).

Additional wildlife food information can be processed by designating wildlife food trees, understory trees or shrubs in the tree classification system as class 9 or 10. Summaries for these special classes provide information on basal area and number of trees per acre or hectare.

Wildlife Habitat Inventory

Information on habitat for some wildlife species can easily be collected as part of forest inventories. Trees that are presently being used as den trees by squirrels or racoons, or trees that could be used as den trees are recorded. In addition, squirrel leaf nest trees or nesting trees for important or endangered birds are included. The Illinois system uses the tree classification system for recording wildlife habitat information. Tree class 5 includes trees with cavities in the upper 1/4 of the stems as den trees for

Figure 3.--Acorn and nut production output

ILLINI STATE FOREST
AVERAGE ACORN AND NUT YIELD BY SPECIES

SPECIES LISTING	POUNDS/ACRE	TOTAL POUNDS
BLACK OAK	2.27	375.00
BUR OAK	0.82	135.00
CHINQUAPIN OAK	2.39	395.00
RED OAK	78.25	12911.10
WHITE OAK	109.62	18087.68
TOTAL ACORNS	193.36	31903.78
HICKORY SP	55.22	9111.73
SHAGBARK HICKORY	51.45	8488.80

squirrels, racoons or other animals. Tree class 6 includes trees with cavities in the lower 3/4 of the stems, and class 7 includes dead standing trees that are useful for wildlife. Class 8 includes squirrel leaf nests and classes 9 to 10 can be used for other wildlife habitat information such as nesting trees. An example for classes 5 and 6 is shown in Figure 4.

Other wildlife habitat information can be inferred from timber information collected. Structure and composition of a forest often can provide valuable information on habitat for a variety of wildlife species.

DISCUSSION AND SUMMARY

The Illinois Forest Inventory Data Processing System has been used successfully during the last year on a number of forest properties in Illinois. Timber, wildlife, and multiple use inventory data were processed. The system has been readily accepted by most field foresters as the input instructions are simple and the output is self-explanatory. Turnaround time will be relatively short as the program can be accessed from several forestry district offices in Illinois through the Mid Illinois Computer Cooperative or with interactive terminals from any location.

The system can be adapted to other forest regions with relatively minor programming changes. For example, the species coding for trees and shrubs can easily be changed. The functions used by the system for predicting acorn and nut production and the equations predicting shrub biomass from basal stem diameters can be replaced with locally derived functions.

The Forest Inventory Data Processing System can provide valuable information on several multiple forest use aspects for forest managers, wildlife managers, and ecologists. The system relieves the user from tedious and time consuming calculations and provides additional inventory information

Figure 4.--Wildlife habitat output

WILDLIFE HABITAT SURVEY
ILLINI STATE FOREST

SPECIES LISTING	BASAL AREA	NO.TREES	AVERAGE DIAMETER
CLASS 5 DEN TREE - UPPER CAVITY			
BLACK CHERRY	0.30	0.17	16.62
ELM SP	0.30	0.11	20.32
SHAGBARK HICKORY	0.30	0.39	11.08
SUGAR MAPLE	0.61	0.43	14.77
RED OAK	0.61	0.45	14.43
WHITE OAK	0.30	0.39	11.08
BLACK WALNUT	0.61	0.73	11.42
TOTAL	3.03	2.67	
CLASS 6 DEN TREE - LOWER CAVITY			
BASSWOOD	0.30	0.39	11.08
ELM SP	0.30	0.11	20.32
SUGAR MAPLE	1.21	0.61	17.63
BLACK OAK	0.30	0.06	27.70
RED OAK	0.61	0.36	16.32
WHITE OAK	0.30	0.39	11.08
BLACK WALNUT	0.61	0.39	15.62
TOTAL	3.64	2.30	

rarely made available by other forest inventory data processing systems.

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Using Short Programs in Natural Resource Inventories[1]

James P. Barrett and David S. Linden[2]

Abstract.--The use of short programs for natural resource inventories with limited or special purpose objectives as an important complement to larger computer systems is stressed. Illustrations include a BASIC program to summarize data from a deer browse survey based on stratified random sampling and a hand computer program to summarize data from a simple timber survey.

INTRODUCTION

Many excellent, large data processing systems for natural resources inventories are available, with some of these systems being described at this meeting. Rather than expensive program duplication, we should use these systems whenever practical. On the other hand, we should retain the flexibility of using and sometimes writing short programs for special purpose inventories or inventories with limited objectives.

About a decade ago computers on university campuses seemed to be off in a corner, used only by computer scientists, some mathematicians, and a limited number of researchers. During this period, President Kemeny of Dartmouth College provided leadership in making the computer a working tool for all the students and all the faculty. This was accomplished by making it readily available, easy to use in solving problems with both long and short programs, and easy to program (perhaps in BASIC or a subset of FORTRAN). In other words, the computer was set up for the user of large or small programs who requires two dollars worth of computing time as well as the user who requires hundreds of dollars worth of computing time. A flexible system including hand computers is essential if foresters are to make maximum use of computers.

Many foresters will have the ability to write such short programs. This will allow the programming specialists to concentrate on the longer programs. In addition, some elementary knowledge of programming will enable foresters to better understand the process and thus communicate more effectively with specialists.

Two examples of short programs are described: A BASIC program to summarize data from a deer browse survey based on stratified random sampling and a hand computer program to summarize data from a simple timber survey.

A BASIC PROGRAM FOR STRATIFIED RANDOM SAMPLING

Anyone who has summarized data based on a stratified random sample knows that it is tedious to compute estimates and standard errors. Yet a short program written in BASIC called STRTRAN provides a quick, easy solution to the problem. STRTRAN is one of nine short computer-terminal programs described by Barrett and Nutt (1975) that can be used to summarize data from sample surveys. These mini programs are a useful supplement to the standard statistical packages available in most computer systems.

Let's look at an example using STRTRAN to summarize a deer browse survey.

A wildlife manager was interested in estimating the total weight of winter deer browse on a 1200-acre forest in the mountains of Virginia. The sample unit was a .001-acre plot. Clipped browse was oven-dryed and weighed in grams for each unit selected. Aerial photographs were used to divide the area into three strata by forest type. A stratified random sample of 48 plots selected by proportional allocation yielded the following data:

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[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tuscon, Arizona, January 8-12, 1978. This study was funded in part by the N.H. Agricultural Experiment Station Research Projects McIntire-Stennis 14 and Hatch 149, and published with the approval of the Director, N.H. Agr. Expt. Sta. as Scientific Contrib. No. 899.

[2]Professor and Graduate Research Assistant, University of New Hampshire, Durham, NH.

Stratum 1 Hardwood 400 acres		Stratum 2 Pine-Hardwood 500 acres		Stratum 3 Pine 300 acres	
$n_1 = 16$		$n_2 = 20$		$n_3 = 12$	
0	8	8	1	2	3
15	0	2	0	7	5
30	12	0	7	0	7
10	37	21	16	0	1
12	18	17	6	12	10
20	10	5	22	7	2
5	0	4	8		
2	28	12	11		
		2	6		
		7	5		

The wildlife manager wants to estimate the total weight of browse on the tract with a .95-confidence interval.

We won't describe the properties of this technique in detail, nor the equations that require tedious numerical calculations. They can be found in textbooks on sampling.

To use STRTRAN, we simply call the program from computer storage and obtain the following instructions:

```
TYPE DATA STATEMENTS IN LINE 1 TO 99:
 POPULATION DESCRIPTION IN QUOTES
 NUMBER OF STRATA, NUMBER OF UNITS IN THE POPULATION
 STRATUM #1 DESCRIPTION IN QUOTES
    NUMBER OF SAMPLE UNITS, TOTAL NUMBER OF UNITS
 THE Y OBSERVATIONS FOR STRATUM 1
 STRATUM #2 DESCRIPTION IN QUOTES
    NUMBER OF SAMPLE UNITS, TOTAL NUMBER OF UNITS
 THE Y OBSERVATIONS FOR STRATUM #2
 REPEAT FOR SUBSEQUENT STRATA
 SEPARATING EACH ENTRY BY A COMMA

WHEN FINISHED TYPE RUN
```

Then we type the data according to the instructions:

```
1 DATA 'ESTIMATING WEIGHT OF WINTER DEER BROWSE'
2 DATA 3,1200000
3 DATA 'STRATUM 1: HARDWOOD',16,400000
4 DATA 0,15,30,10,12,20,5,2,8,0,12,37,18,10,0,28
5 DATA 'STRATUM 2: PINE-HARDWOOD',20,500000
6 DATA 8,2,0,21,17,5,4,12,2,7,1,0,7,16,6,22,8,11,6,5
7 DATA 'STRATUM 3: PINE',12,300000
8 DATA 2,7,0,0,12,7,3,5,7,1,10,2
```

And within a few seconds we obtain the following solution:

```
ESTIMATING PROPORTION ?NO
NEED INSTRUCTIONS ?NO

ESTIMATING WEIGHT OF WINTER DEER BROWSE

THE EFFECTIVE DEGREES OF FREEDOM ARE 30
T VALUE ?2.042


FOR ALL STRATA

MEAN:  8.8125
CONFIDENCE INTERVAL:  6.44703 TO 11.178

TOTAL:  10575000
CONFIDENCE INTERVAL:  7.73644E+6 TO 1.34136E+7

NEED DETAILS ?YES
STANDARD ERROR OF STRATIFIED MEAN:  1.15841
STANDARD ERROR OF TOTAL:  1.39009E+6

STRATUM 1 STRATUM 1: HARDWOOD
STANDARD DEVIATION            11.2692
MEAN                          12.9375
STANDARD ERROR OF MEAN        2.81725
TOTAL                         5175000
STANDARD ERROR OF TOTAL       1.12690E+6

STRATUM 2 STRATUM 2:PINE-HARDWOOD
STANDARD DEVIATION            6.60144
MEAN                          8
STANDARD ERROR OF MEAN        1.4761
TOTAL                         4000000
STANDARD ERROR OF TOTAL       738048.

STRATUM 3 STRATUM 3: PINE
STANDARD DEVIATION            3.96194
MEAN                          4.66667
STANDARD ERROR OF MEAN        1.14369
TOTAL                         1400000
STANDARD ERROR OF TOTAL       343107.
```

Thus, we estimate a total of 10,575,000 grams of deer browse on the tract with a .95-confidence interval from 7,736,000 to 13,414,000 grams. Note that stratum statistics are also given. In many practical situations, estimates within each stratum are more important than estimates for the entire tract.

A HAND COMPUTER PROGRAM FOR A SIMPLE TIMBER SURVEY

An experienced woodsman often will ask a young forester, "How many board feet of timber are in this stand?" He enjoys asking this question because he knows the wide range in answers that he can receive. Numbers per acre such as volume, basal area, trees, or acorn yield are abstractions from an infinitely complex environment to serve some special purpose. By the use of hand computers in the field we can develop a stronger number sense -- a mental association between the forest environment and the numbers we collect. This number sense could lead to new and more suitable measurement techniques.

Use of hand computers in the field is relatively new. Jager (1976) describes a program for field use with the Barr and Stroud dendrometer; Satterlund (1977) describes how to locate shadows with a hand computer.

Let's look at MINICRUISE[3]--a simple program to summarize data from an angle-gauge survey. The program, written on a Hewlett-Packard 65 hand computer, provides estimates of basal area,

[3] The reader may obtain a listing of MINICRUISE or STRTRAN from the authors.

trees, and volume per acre for each sample point and average estimates for all sample points. MINICRUISE requires 95 elementary statements. An equivalent BASIC or FORTRAN program would require about 25 statements.

To illustrate how to use MINICRUISE in the field, suppose that a forester together with a landowner plans to inventory a white pine stand with an angle-gauge. First the forester reads in the magnetic program card containing MINICRUISE. Then, after entering the basal area factor, the forester is ready to begin the inventory. At each point the forester enters the DBH and merchantable height in 16-foot logs for all sample trees. (The program was written so that the computer is ready to accept DBH by displaying 8888 and height by displaying 1065.) After entering all trees at a sample point, the forester presses three function keys to obtain basal area, trees, and board foot volume estimates per acre. He records the information on a tally sheet. The forester then presses an "end of point" function key and repeats the procedure at the next point. After all points have been sampled, the forester presses an "end of cruise" key to obtain average per acre estimates for all points. Then the average estimates of basal area, trees, and volume are obtained by pressing the same function keys used to obtain individual point estimates.

Let's look at the results of an inventory of only six points (generally we would want more than a dozen points). On the six points we selected 55 trees. Instead of having a tally of 55 indiscernable dots and dashes, we have seven lines of information readily understandable in the field:

OWNER C. Stafford DATE 11/15/77

TRACT Roadside Pine PAGE 1 of 1

POINT	BASAL AREA	TREES PER ACRE	VOLUME[4] PER ACRE
1	220	1173	8750
2	180	1722	3125
3	200	1535	3750
4	100	495	1875
5	220	850	5000
6	180	1017	1875
mean	183	1132	4063

[4]Volume per acre = 62.5 (basal area factor) (sum of logs of trees tallied at sample point)

As they stand in the field, the forester and landowner not only have an estimate of the mean basal area, trees, and volume per acre, but also how these estimates vary among individual points over the tract.

Some of the newer model hand computers have much larger memory capacities. This will allow larger and more powerful programs to be developed. MINICRUISE could be extended to give estimates by tree classes with standard errors.

CONCLUSIONS

Short computer programs complement the large computer systems by providing:

(1) quick solutions to many limited or special purpose inventories,

(2) a greater opportunity for combining the speed of computation with intuitive judgment -- that is, greater machine-man interaction, and

(3) greater opportunity to detect incompleteness or flaws in field measurement techniques.

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Error Processing Systems for Integrated Resource Data[1]

William O. Rasmussen[2]
and
Peter F. Ffolliott[3]

Abstract.--A system of computer programs has been assembled to allow production of land suitability maps, i.e., graphical displays of numerical ratings of land for alternative management activities. One aspect of this system concerns the checking for any inconsistancies in spatially distributed data fields. Several graphic display modes for analyzing these inconsistencies are presented.

INTRODUCTION

Over the last decade, land use planning has witnessed a large increase in both awareness and concern by the general public and land administering agencies. During this same period, many techniques and tools have been developed to assist land planners. The increased complexity and sophistication of the problems presented to the land planner have required that all information known about land areas be used in developing accurate and comprehensive answers. One tool which is proving quite useful in meeting this end is the production of suitability maps of land relative to various activities.

A suitability rating is derived by comparing the necessary conditions needed for a proposed activity against the physical and biological parameters associated with the land. The tool is comprised of a system of computer programs which are interfaced to allow operation in an interactive mode. The entire system has been designed for ease of operation by a land planner or his computer aide. The system is now being used on problems encountered by Cochise County Planning and Zoning Department in the State of Arizona. It is also being used experimentally for unit and forest planning by the USDA Forest Service.

Before examining the requirements and error checking componnets of the system, the data analysis and display elements are presented.

DATA ANALYSIS AND DISPLAY

The system of programs is designed to operate on a multi-topic cellular data base. A display computer program is used to produce a printer map of:

1. any single data topic;
2. the addition, subtraction, multiplication, or division of one data topic by another;
3. percent suitability of the area relative to any activity; and
4. designations of suitable and nonsuitable areas for a given activity.

Statistical summaries of selected data arrays can be generated without producing any maps. These summaries contain the amount of area in each of up to 50 data levels and the percent of the entire area in each level. If the summaries show that the associated map would be useful, it can be produced. If it is found that the summary is sufficient or that the output data array is not what was expected, the cost and time of map production is saved.

Some of the topics in the data base are generated from other topics by use of appropriate computer programs. The slope and aspect topics are derived from the elevation topic. Solar radiation loading for a winter and a summer day

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[1]Paper presented at the Integrated Inventories of Renewable Natural Resources Workshop, Tucson, Arizona, January 8-12, 1978.

[2]Assistant Research Professor, School of Renewable Natural Resources, University of Arizona, Tucson.

[3]Professor, School of Renewable Natural Resources, University of Arizona, Tucson.

can be derived from the slope and aspect data. Distance to the nearest water source for each cell comes from the appropriate operation on the stream channel and water body data topic.

The analysis computer program can produce suitability surfaces for defined activities input by the operator. For example, one activity may be the construction of a campground. Some of the constraints for this activity may be well-drained soils, gentle slope, and other appropriate items. The output suitability map shows the study area locations which have the required combinations of data parameters to allow them to be classed as suitable for that activity. An activity can have up to six constraints on each data topic. Then, the program examines the data characteristics associated with each cell. If all conditions outlined in the activity are met, the cell is assigned the value 1.0. If less than all constraints are met, the cell is assigned the value of the ratio of met constraints to total number of constraints. The output map may be one of two forms. One map shows cells which were entirely suitable coded by one symbol and all other cells assigned another symbol. Another map output is assigning the value of the ratio of activity constraints met to total number of constraints for each cell to each cell.

Maps of area overlap by two activity suitability arrays may also be produced. These maps show the acreage and location of areas which were rated suitable for two activities.

DATA NEEDS AND SOURCES

As previously stated, the system of programs is designed to operate on a multi-topic cellular data base. Data used to generate the topics of the data base are often collected in several manners by separate agencies each of which have collected only one or more of the data topics that are contained in the main data base.

For example, some of the data for a sample watershed were collected at selected sampling points on the area. Other topics were collected using transects across the watershed. Much of the data were coded in the field on data pads. These means of obtaining data do not facilitate easy comprehension of trends or spatial inconsistancies in the data. Plotting of the data on a field map containing the sample points would show any strong spatial deviations in the data which have been collected. If there are deviations which are considered to be inappropriate for the area and particular data topic, additional data can be obtained promptly.

Often, data are not pre-examined in the field. The examination for any inconsistencies is handled by the agency before it releases the data or possibly left to the potential data user. All new data should be checked for spatial consistency.

ERROR CHECKING

Errors in data sets may arise in several ways. The original field observation may be in error, the measurement may have been written down incorrectly, the wrong sample point number may have been assigned to the item, or errors may have been committed when transfering the data from its field form to the form used for storage in the computer.

Checking large arrays of data manually for errors is a process which may allow errors to pass through, particularly if a large amount of time is not allocated.

In the system of programs, a data base is composed of 20 or more data topics. Some of the topics are created by interpolation of field data associated with an irregular grid of field sample points to an array of values associated with a uniform grid configuration. The interpolation is conducted using SYMAP (Dougenik 1975) or a similar computer program.

Computer programs are available in the total system which allow data to be visually scrutinized for errors by examining either graphic displays of the interpolated field data or printer maps of the deviations between the field data and computed trend surfaces.

The analysis program may perform mathematical operations or do selective filtering of the data topic array. Any errors in a data base can be conveyed and possibly intensified in the output suitability maps. Due to this error transferral, data stored in the data base needs to be as clean or error-free as possible. Each element of the field data has its value associated with not only the cell containing the sample point, but with neighboring cells. This means that the field data values should be as correct as possible. In the occurrence of an erroneous field data value, not only the cell at the location of the field sample point would be incorrect, but also those cells in the general neighborhood in the resultant interpolated data array.

The field data may be interpolated to a uniform grid and displayed as a shaded gray printer map (Figure 1). The higher data values are assigned symbols which have a darker appearance on the output map than those assigned to lower values. The interpolated data may also be displayed as a three-dimensional perspective plot (Rens 1971) to show dramatically any discontinuities in the general character of the data

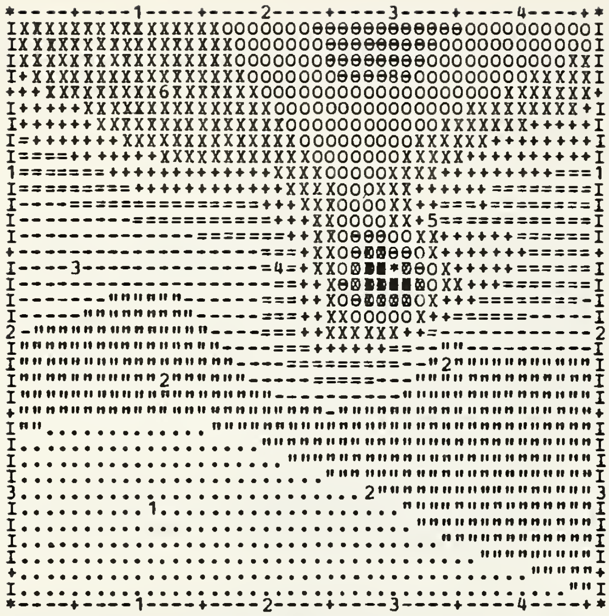

Figure 1 -- Shaded grey printer map of the interpolated field data. Darker areas represent higher values.

topic surface (Figure 2). Additionally, contour maps (Beharrell 1976) may be produced from the field data to show gradients in the data caused by large errors (Figure 3).

One error checking program uses a trend surface produced from the field data (O'Leary 1966). In essence, the trend surface is a

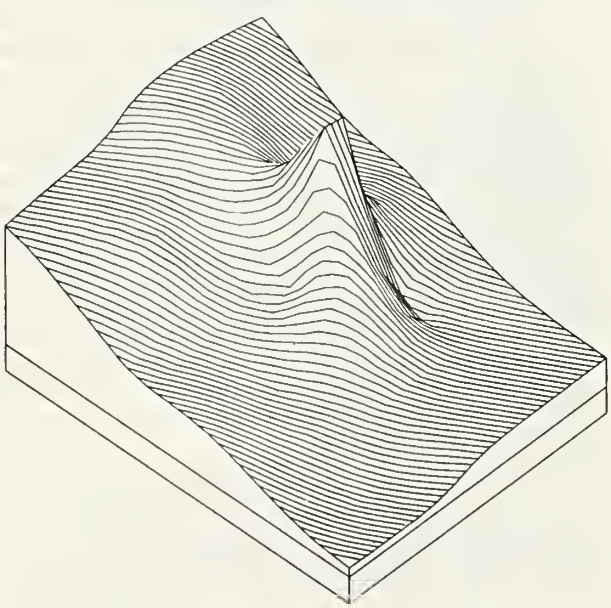

Figure 2 -- Three dimensional perspective plot of the field data. Higher points represent large values.

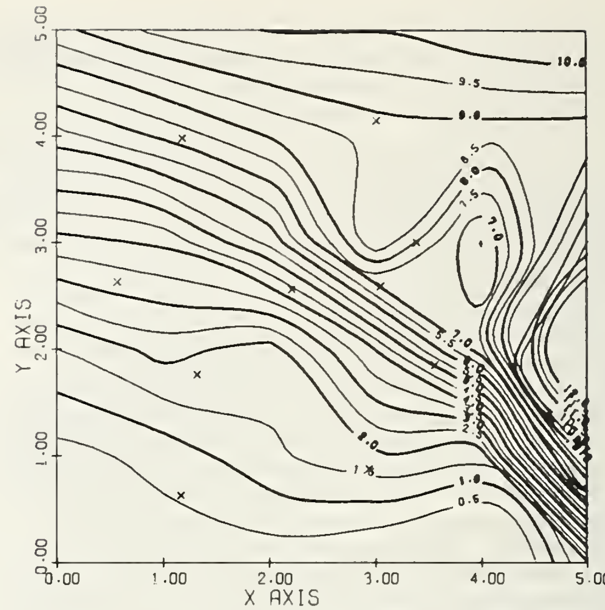

Figure 3 -- Contour map of the field data.

mathematical function which gives the regional average of the original data at any location on the watershed. The trend surface functional forms which have been used to date are first- through sixth-order polynomials. Errors are defined as deviations greater than a given amount in residual maps of the difference between the regional average (trend surface value) and the interpolated field value (Figure 4). Locations which have high deviations are coded by darker symbols on the output map. Row

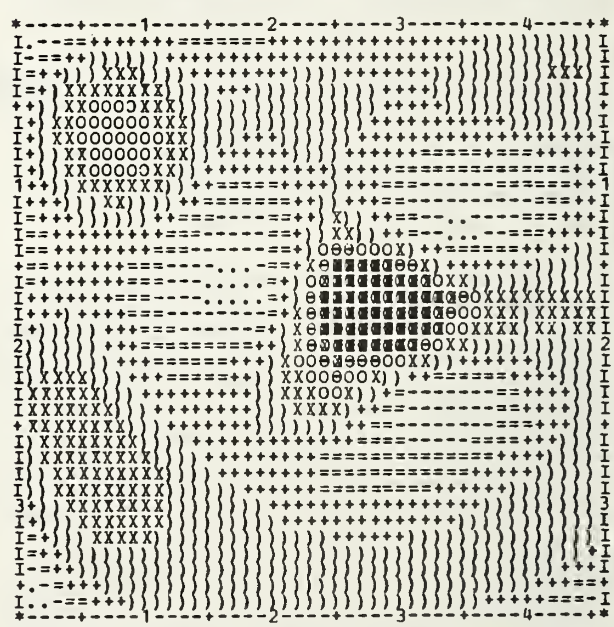

Figure 4 -- Residual map between the 4th order trend surface and the interpolated field data.

and column coordinates are presented on the output along with the magnitude of the deviation. The threshold value above which errors are declared depends on the nature of the data topic being examined. For example, percent ground cover might be expected to have greater spatial variation than dominant overstory type in certain areas. Associated with the greater spatial variation of percent ground cover might be larger deviations between the trend surface and measured values of this variable.

The original field data may be reduced by selected removal of data points which have deviations greater than a predetermined amount from a trend surface of the area. Then, a new trend surface may be computed from the remaining values and a lower tolerance set for deviation of the remaining data from the new surface, resulting in a further reduction in the usable number of the field data items. The final filtered field data set is input to a program which in turn, interpolates from this data to values at all locations in a uniform spatial grid. This interpolated data array is used as the corrected data topic in the main data base. Similar operations are performed on all appropriate data topics.

SUMMARY

Several graphic formats have been used to display spatially distributed data. These displays allow quick and inexpensive examination of entire data fields for inconsistencies or questionable values. The human eye can observe trends in the data and mentally flag any points which do not appear to fit the texture of the data surface. Trend surface techniques allow one means of checking a data array for points which do not fit apparent trends in the data. These points may be correct but are flagged as possible errors. Local fluctuations in a data array do not necessarily mean that the points are in error; in geophysics, for example, they could be indicative of a copper ore body.

The land use planning tool presented has the ability to check data points in the associated data base for inconsistencies. This check is felt to be a useful feature for a system of this nature. Land suitability maps of an area can have greater verity when they have been produced from data which have been checked for errors.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the able computer programming assistance by Alma Sperr and David Beaver.

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FINSYS — A Tool for the Processing of Integrated Resource Inventory Data[1]

Joseph E. Barnard[2]

Abstract.--Resource inventory data processing requires quick, low-cost procedures for developing desired information. A computer system--FINSYS--is presented here. It is a generalized system with the flexibility to allow the user to specify the procedures for both data handling and table construction. The components of the system are described, and its development and use since 1964 are discussed.

What is FINSYS? The name is an acronym for Forest INventory SYStem. FINSYS consists of several computer programs that function as a flexible vehicle to convert large masses of data about the inventory of some resource into specific, user-defined tables of statistical information (totals, variances, and sampling errors). It was developed and is maintained by the Northeastern Forest Experiment Station, U. S. Forest Service. The user of FINSYS can accomplish a particular task by using one of the several subsystems. These are:

EDIT--To edit unit records, perform desired calculations on these records, and make one-dimensional tables of desired data.

TABLE--To form tables of means, variances, and covariances from plot data, using user instructions regarding table format, size, and content.

OUTPUT--To expand the data from TABLE according to appropriate sampling formulae and to print tables of data with title, row, and column headings.

Both EDIT and TABLE are flexible as to the format of input data, the specific tasks to be accomplished, and mode of output. The OUTPUT subsystem always functions with the TABLE subsystem to produce final data tables in hard copy. Figure 1 depicts a generalized flow of the entire system. Documentation and operating instructions are given in a series of publications.[3] Additional information and source decks of the three programs are available upon request.[4]

A brief discussion of each subsystem is presented here to illustrate the function of the system.

EDIT

EDIT is an independent editing and file-updating subsystem of FINSYS. It is designed to apply to a file a specific set of data checks and cross-checks, record by record. There is also built into it the capability to generate new information and to develop one-dimensional tables of output. As the program is executed, individual inventory records are compared with the criteria established by the user, and new data fields are incorporated as part of the unit record.

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[1] Paper presented at the Integrated Inventories of Renewable Natural Resources Workshop, Tuscon, Arizona, January 8-12, 1978.

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[3] Wilson, R. W., and R. C. Peters. The Northeastern Forest Inventory Data Processing System, USDA Forest Serv. Res. Papers NE-61 and NE-70 to 78. 1967.

[4] Write Carl E. Mayer, Project Leader, Resources Evaluation Project, Northeastern Forest Experiment Station, 6816 Market Street, Upper Darby, Pa. 19082. USA

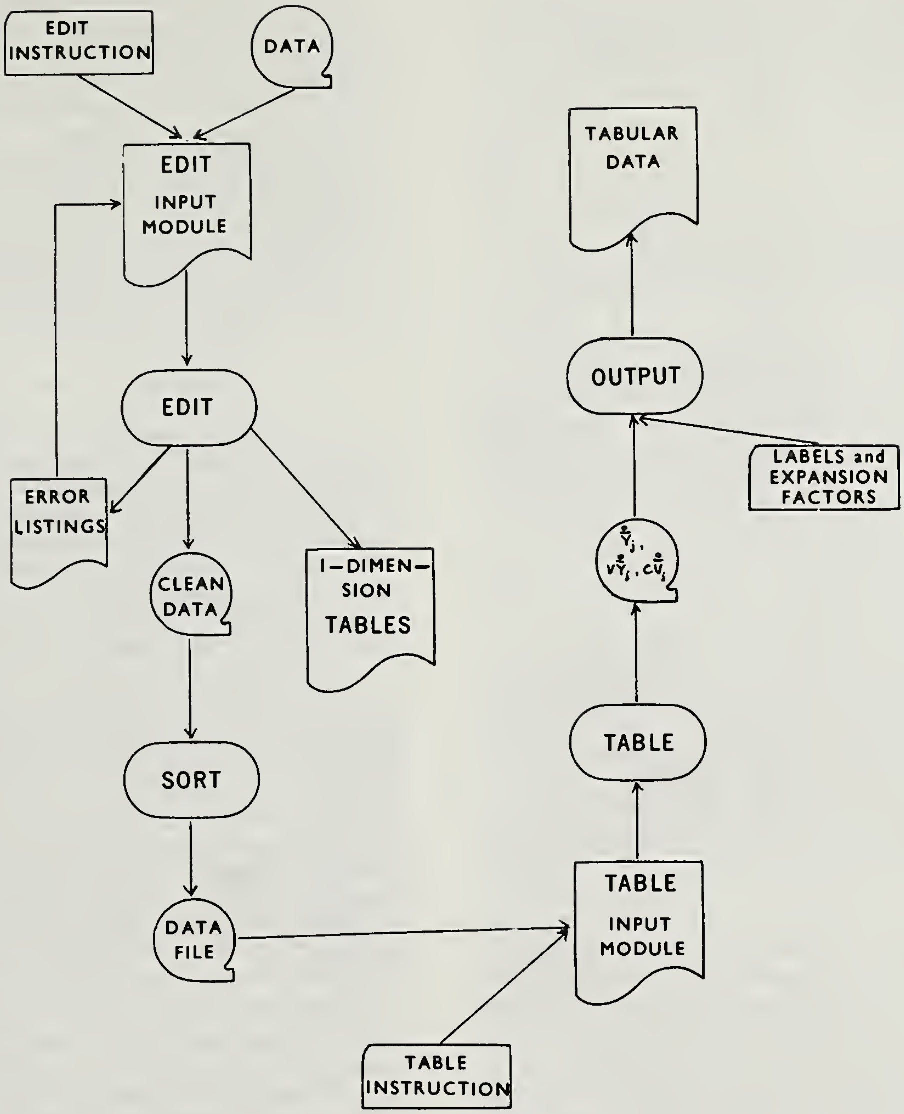

Figure 1.--A generalized flow of FINSYS

Possible errors are flagged, and correct records are written on the desired output medium. Correction of flagged records must be accomplished outside the system. The corrected records can be passed through EDIT separately. Data-file regrouping can be accomplished by standard techniques. All input records must be of fixed length. Output is also in fixed-length records, but these need not necessarily be the same length as the input records. Format of the records is free, and must be established by the user for the particular edit job.

EDIT includes a translator. The language consists of 11 verbs. The compiler translates these verbs into action codes to be executed during a specific processing run. The use of EDIT consists of writing instructions with these verbs and the associated data fields.

Perhaps the use of EDIT can be demonstrated best with an example. Imagine an inventory consisting of a random sample of 1/10-hectare ground plots on a 10,000-hectare forest tract. On each ground plot, sample trees were tallied according to species, diameter at

breast height (dbh), merchantability class, and log-quality grade. Additional resource data were tallied for the stand in which the plot was located. An EDIT of these data might be developed to accomplish the following:

1. To check for legal resource codes.
2. To check the bounds of dbh. A dbh less than 10 cm or greater than 100 cm will be considered a possible error.
3. To check the bounds of the tallied heights. Merchantable heights greater than 30 meters will be considered possible errors. Merchantable height will be compared with sawlog height, to verify that sawlog height does not exceed merchantable height.
4. Tree merchantability will be compared with log-quality grade. Classification of a tree as a cull and assignment to it of a log-quality grade other than cull will be considered a possible error.
5. Volume of the tree in cubic meters will be calculated from appropriate formulae or tables.
6. Plot summaries of volume will be developed on a plot basis.
7. Correct records, including the calculated volumes, will be put on tape.

It should be obvious that EDIT is a complete package. It can be, and has been used to provide a complete data-processing vehicle for a specific purpose. The provision for calling a specific user-written FORTRAN subroutine adds to the capability and flexibility of EDIT in the hands of a user with programming talents.

TABLE/OUTPUT

TABLE and OUTPUT are two dependent subsystems that, in combination, develop desired statistical summaries and print these with the appropriate labeling. TABLE reduces the file of unit record data (usually, but not necessarily, developed in EDIT) into one- or two-dimensional arrays (tables) according to specifications supplied by the user. Data in these arrays are stored as means, variances, and covariances of totals, according to the appropriate sampling option. TABLE will accomplish the necessary statistical computations for complete enumeration, simple random sampling, and stratified sampling with strata of known or estimated size.

TABLE also has a translator. The language consists of five verbs and two nouns. Tables are developed by matching the appropriate verbs with the data field to be used. The two nouns are used to recognize areas of activity.

OUTPUT accepts the arrays developed in TABLE, performs any necessary stratum weighting and expansion calculations, and prints final results in acceptable table format. OUTPUT will develop grand-totals tables on request when tables for several geographic regions are being processed as a single run.

DEVELOPMENT OF THE SYSTEM

The idea of the computer dictating the method of inventory and the kind and amount of statistical output is repugnant to most people. Nevertheless, such dictation happens all too frequently. The philosophy underlying the development of FINSYS is: "The computer should be the tool by which the user can quickly obtain the data he wants in a form he can use." The essential requirement is flexibility.

It is interesting to trace the development and application of this concept. In the mid-1950's, C. A. Bickford and William O'Regan, biometricians at the Northeastern and Pacific Southwestern Forest Experiment Stations, respectively, of the U. S. Forest Service, both recognized the necessity of developing a complete package of efficient computer programs to process the increasing volume of forest-inventory data being gathered by Forest Survey and others. Both men envisioned a system in which the computer would rapidly convert field-tally data into final totals of volume or area. One essential requirement of this system would be a provision for calculating statistical data, including variances and sampling errors.

In 1960, the Forest Survey Project of the Northeastern Forest Experiment Station, under the leadership of Carl E. Mayer, teamed with a biometrics group composed of Bickford, Robert Wilson, and Robert Peters to begin developing a computer system for processing forest-inventory data. The initial effort of this group was a series of programs to process the data from the forest survey of West Virginia. This survey utilized both remeasured 1/5-acre sample plots and newly established, variable-radius clusters of points for estimating the timber resource of the state. In March of 1963, the computer produced a series of 28 tables giving various totals and breakdowns of the West Virginia data.

In the interim, the Forest Survey field staff had completed its work in Maryland.

Now the job of processing these data began. Immediately, the processing staff realized that the output tables desired for Maryland differed somewhat from those for West Virginia, and that reprogramming was required. A decision was made to develop a flexible system that would accept instructions for data format, table makeup, etc., as input along with the data to be processed. This capability would eliminate the necessity for detailed reprogramming for each new inventory, and would release the Forest Survey technical staff to pursue other, more important, details of inventory planning and techniques.

MAINTENANCE OF THE SYSTEM

FINSYS is programmed in FORTRAN IV for batch processing. The original programming was done on an IBM 7094 system. During the next 10 years, conversions were made to the IBM 360 and 370 series, the Univac 1108, the RCA Spectra 70, and CDC 6400 and 6600. In 1972, Dr. W. E. Frayer performed extensive reprogramming on all three subsystems. This work was done at Colorado State University under contract with the U. S. Forest Service. The revised subsystems developed by Frayer reflect no change in the basic philosophy of each. They do, however, provide some additional capabilities to the user.

For anyone interested in operating times, here are some benchmark figures for the IBM 370/168 (OS 21.2 with HASP). EDIT processes more than 6,000 records per minute of CPU time through rather complicated edit procedures. TABLE and OUTPUT combined process more than 10,000 records per minute of CPU time when developing more than 20 different tables. These times pertain only to a particular computer; actual times will vary with machine configuration and the specifics of a particular processing run.

The minimum computer hardware requirements to operate FINSYS are:

1. A central processing unit with at least 32K word (32-bit or larger word length) core memory.
2. Card read and card punch capability.
3. Disk or tape input/output capability. If the system is restricted to tape capability, a minimum of three tape drives is required.
4. High-speed printing capability.

EXPERIENCE WITH ITS USE

The impetus for the development of FINSYS was the need of the U. S. Forest Service for a more efficient data-processing capability for its nationwide forest inventory. Beginning in 1964, FINSYS has been used at five of the six Forest Survey project locations to process the inventory data. As familiarity with the system increased, various National Forest regions began to use FINSYS to process the data from inventories of the various National Forests. The use of the system has increased every year.

I can be more specific about the use of the system by the NEFES's Forest Survey Project. FINSYS was used for the entire second cycle of forest inventories on the 105 million acres (42.5 million ha) of forest land in the 14 northeastern states of the United States. The third cycle of forest inventory is now underway, and resource statistics have been developed with FINSYS for more than 25 million acres (10 million ha) of forest land in four states. Through all this, FINSYS has provided data in a timely manner with the necessary flexibility to meet the changing needs for specific resource statistics.

In the decade since FINSYS source programs were first made available to interested users outside the U. S. Forest Service, there have been many interesting applications. FINSYS has been incorporated into the continuous forest inventory program of Canadian International Paper Company for more than 16 million acres of forest. Graduate students at Iowa State University have used FINSYS as a research tool to study sampling theory through repeated sampling of a population resident in the computer data bank. FINSYS has also been coupled with a forest simulator to provide more detailed update estimates for a forest. FINSYS is truly multilingual. Recently, FINSYS was used to develop inventory estimates in Spanish for the first forest inventory of Paraguay. Other applications have produced tables in English, French, German, and Spanish, without modification of the source program.

CONCLUSION

What really matters in resource-inventory data processing is the ability to develop the desired inventory information quickly and at relatively low cost. FINSYS is a generalized processing system that has met these requirements in a noteworthy manner during the past decade. Not only has it met individual users' immediate needs, but it has also shown an ability to grow with the user. I believe that its utility will continue to increase in the next decade. Since it is essentially a unit-record processor for <u>any</u> data, I anticipate its increased use in a variety of inventory applications as more potential users learn of its capabilities.

Data Processing Systems for Small Ownerships[1]

James C. Space[2]

Abstract.--The development of generalized data processing systems for forest inventories first applied to the job of processing large volumes ~~of~~ data, has been extended to inventories of small ownerships in recent years. For many users, the advantages of such systems may lead to significant cost and time savings over custom-written programs. Although no one system includes all desirable features, improvements are constantly being made. The next logical step, already being tried on a limited basis, is to apply these techniques to integrated inventories.

INTRODUCTION

Until fairly recently, the customary method of using automatic data processing was to write a custom-written program for each application. This poses some special problems in the case of data processing for small ownerships. Usually the resources of the small landowner are limited, his use of such systems is infrequent, and he is dependent upon assistance from a variety of consultants, extension specialists, and service foresters. Furthermore, the needs of small landowners vary greatly from area to area. This makes it extremely difficult to develop custom-written programs which will meet these needs and yet can be amortized over a sufficient volume of use to be cost-effective. Fortunately, over the past few years we have seen the development of a number of generalized data processing systems which are applicable to the needs of the small landowner.

I intend to limit my remarks to programs which are generalized in nature; that is, they can be used under a variety of conditions and on a wide range of computer makes and models, as opposed to most computer programs which are written to do a specific, limited job. Such general programs, although they may be somewhat less efficient from a strict data processing standpoint, permit bypassing many of the costs of program development. Such programs are not a panacea, however. They are merely tools which aid the forester or land manager in doing a better job, either in managing small tracts of land or aiding the small landowner. They should be evaluated, therefore, strictly on the basis of whether or not a better, more professional, and more cost-effective job can be done if they are used.

ADVANTAGES AND DISADVANTAGES OF GENERALIZED SYSTEMS

Perhaps the foremost advantage of generalized data processing systems is their potential savings in development costs. Anyone who has been involved in the development of computer applications recognizes that, as computer speeds have increased and the price of computer hardware has decreased, the development and maintenance of applications programs (commonly called "software") has become the major cost item in data processing. While the cost for development of a generalized system may be greater than for a custom-written application, this cost can generally be amortized over a longer period of time and a greater volume of use. Furthermore, many of these programs have been developed by universities or government agencies and are available free of charge or for a small fee to pay for reproduction.

Some programs, because of their wide area of applicability and the talent and resources

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[2]The author is Director, Computer Systems Applications Staff, U.S. Forest Service, Washington, D.C.

which have been expended in their development, have features available which might be impractical or too costly to develop for an application with limited use. Furthermore, most of these systems are under continuing development and additional features are added to accommodate special needs as they arise.

Because they must operate on a variety of computer makes and models, these systems generally are largely independent of hardware considerations. They are usually written in a standard subset of a higher-level computer language (generally FORTRAN) so that they will operate on almost any computer having this capability with only changes in the job control language necessary to set up and run the job.

These programs, or at least their commonly-used options, are usually thoroughly debugged and error-free before they are released for public use. This can be a considerable savings to the program user, both in the cost of chasing down and correcting program bugs and in frustration in getting the job done.

These considerations enable the user to acquire and use one of these systems with really very little knowledge of computers or programming.

Generalized systems also have a number of disadvantages which must be considered as well. One characteristic of such programs, which must accommodate a variety of users, is that they tend to be bulky and filled with what often seems to be an overwhelming array of options. Furthermore, some of these options, or combinations of options, may have never been used thoroughly enough to be completely debugged. Generalized programs are usually less efficient from the standpoint of the use of computer time, although this is becoming less and less of a consideration. Since these programs are written to appeal to a large number of users, they tend to use compromise solutions to problems. There are always a number of things that you would do differently if you were developing a program just for your use. If modification must be done, the complexity of many of these programs makes modification difficult. Perhaps the greatest danger, though, may be the tendency of some general-purpose programs to promote the use (or misuse) of techniques which are poorly understood by the user. Many of these programs incorporate the development of regression equations, or the use of linear programming or goal programming. The use of these techniques, and others, without adequate training or understanding on the part of the user can lead to erroneous conclusions. Program developers should try to constrain the possibilities of misusing such techniques as much as possible in developing their programs, but it is still incumbent upon the user to make sure he understands the underlying assumptions of the program.

EVALUATION OF COMPUTER PROGRAMS

An evaluation of computer programs for use in inventory and management planning on small ownerships was conducted by Space, Balmer, and Lund (1976). This study identified and evaluated a number of computer programs which could be used by service and consulting foresters in the development of management plans for tracts less than 1,000 acres in size. Programs evaluated fell in the general areas of timber stand accounting, cruising and/or inventory, financial analysis, and resource allocation modeling. Only non-proprietary programs were considered.

To be considered, programs had to be sufficiently general in nature that extensive reprogramming was not necessary, have instructions clear enough to be used by the typical service forester or consultant, and well documented so that making necessary changes would not be an insurmountable problem. The facilities and procedures necessary for use of programs by field personnel were also a major consideration.

EVALUATION CRITERIA

A number of programs which apparently met these broad specifications were identified. The programs were further evaluated against the following criteria:

Does the program fulfill a need in aiding the forester by saving time, enabling him to do a more professional job, or facilitating better management of the land?

What are the economics of operating the program, including both direct and indirect costs?

Can the program be used by people who are unfamiliar with computer operations, coding of forms, etc?

Can program output be easily interpreted by the forester and, when incorporated in a management plan, by the landowner?

Is use of the program from field locations practical or would mail delays, communications problems, or special equipment needs limit use of the program?

What facilities, equipment, and programming support are needed to operate the program?

Is the program in a standard subset of a common programming language so that it can be operated with only minor adaptions on a wide range of makes and models of computers?

Is the program small enough in size or structured by means of overlays so that it can be operated on the small- and medium-sized business-oriented computers commonly available to states and consultants?

Is documentation complete and usable?

Can changes be readily made by programmers who are not familiar with the program and with forestry problems?

As would be expected, none of the programs investigated met these criteria perfectly, although several came surprisingly close. All the systems examined would require some modifications by a programmer for use in other areas or states, but some systems are easier to modify than others. All systems had some type of edit and table generation programs. Generally speaking, in all systems there were no provisions for modifying the format of the tables produced or for having new tables compiled, although several systems did have optional tables. The mail is used for submitting data and receiving program output unless remote job entry terminals are available. All systems require a keypunch, cardreader and line printer. All had input forms that could be readily understood and completed by a forester without computer background and all the systems generally produced output which could be easily understood.

STAND AND COMPARTMENT ACCOUNTING PROGRAMS

Stand accounting or record-keeping programs keep track of data which has been collected on each stand such as area, timber volumes, treatment opportunities and silvicultural prescriptions, land use, and treatments scheduled and performed. Various sampling schemes can be used to collect this data but are generally not part of the system itself. These programs are mainly of interest in the management of large properties and have limited utility to service foresters and consultants. In looking at these programs, it was apparent that the data needs of each organization differ so much that it is seldom possible to apply a system developed for one organization to another without extensive modifications. Although a number of systems were identified (Nyland, 1968; Beaufeaux, 1975; Hickok, 1976; Rose, 1976) none of them were of a truly generalized nature.

The utility of computerized record-keeping systems such as this in the management of small landholdings is probably marginal at best. A manual system would probably be more efficient. If a computer-based system is needed, a better approach in many cases might be to use one of the many data base management systems which are now available. Criteria for development of a stand inventory and record-keeping system are given by Meteer (1975).

CRUISE AND INVENTORY ANALYSIS PROGRAMS

Cruise programs, because they deal with individual trees and use commonly accepted mensurational methods, are of greatest potential use by service foresters and consultants. The elimination of time-consuming computations and the ability to use some of the more efficient, but more complicated, inventory techniques also makes these programs attractive.

The main differences among these programs lie in the scope of the input they will accept, computations they will perform, and the output they produce as well as their adaptability to different computer models and to use in different sections of the country. For the most part, they are strictly oriented toward volume computations for cruises and inventories. None of the programs incorporates less frequently used sampling schemes such as 3P, cluster, or variable-probability line sampling.

Survey

SURVEY is a timber inventory system developed at the University of Massachusetts and designed to be used by service foresters and consultants (Mawson and Gornowski, 1968; Mawson, 1975.) It consists of an edit program and a table generation program. SURVEY can be used for small to medium-sized forest tracts (generally less than 20,000 acres) to generate stand and stock tables, total volume summaries, and silvicultural treatment and statistical analysis tables. The system allows inputs from line plots, fixed-area plots or from point sampling. Through use of a "checklist" the system is highly adaptable and useful under different conditions and situations.

The system gains its flexibility from its input scheme. An "inventory checklist" of 10 pages specifies all the limits and/or constraints of the data. This checklist is used to specify variable species names, method of volume calculation, product codes, silvicultural treatments, radial growth by species and diameter class, and acreage figures by forest type. Plot data is input from field tally sheets and includes tree number, species, diameter, height to nearest half log, soundness class, product class, silvicultural treatment,

and crown class. Several of these items are optional. Other desirable features are the ability to handle stratified sampling and to summarize data for a number of tracts. A unique feature is provision for adapting the program to make city tree inventories.

Vermont Forest Inventory Program

The State of Vermont, Department of Forests, Parks and Recreation, operates an inventory system which is available for public use either through services offered by the State or through purchase of the programs (Meyers, et al, 1973; Patunoff, 1974). The system consists of two programs; FORCHK, a data editing routine, and FORIN, a forest inventory summary program. FORIN summarizes and calculates stand and stock tables from point samples taken in the field. Standard errors of estimate are also calculated. Tree input data from a field tally sheet consists of rings/inch, DBH in 2-inch classes, sawlog length to the nearest 4 feet, pulpwood length to the nearest 4 feet, species, a tree classification code, a damage type code, and a percent cull code. Provision is also made for recording deer activity. One input form must be completed for each point visited.

Output consists of stand and stock tables, condition class estimates, and growth information for each stratum. Annual percent growth per acre is calculated by Schneider's formula. The program is limited to 99 point samples within each stratum and a maximum of six strata, but these are probably not serious limitations for most uses of the program. The biggest drawback is that it is limited to point sampling and the user is further limited to use of a 10 BAF point unless the control cards are changed. However, service foresters and consultants using point sampling may find this program of use.

Purdue Forest Data Processing Service

Purdue University, Department of Forestry, in cooperation with the Indiana Department of Natural Resources, has developed a data processing service for forest inventories that implements the more common sampling techniques (100-percent tally, variable-plot, or fixed-plot cruising) used by consultants and service foresters, calculates growth estimates, and provides a list of primary wood-using industries in the vicinity of the sampled tract (Moser, 1970 and 1972). The system is user-oriented and requires only a minimum knowledge of data processing and essentially no familiarity with computer operations. The system consists of modular processing sub-programs and utility functions under the supervision of an executive program. The program is completely debugged and has been operated for a number of years, both by Purdue and the State of Indiana. Although the program would have to be modified for use in another area because of specific input coding used in Indiana, the modular system of processing subroutines should lend itself to modification by an experienced FORTRAN programmer at minimum cost. The user must complete a "Forest Processing Service Request Form," one of five different color-coded "Data Sheets," and an optional "Increment Boring Data Sheet." The request form essentially spells out the sampling scheme used and provides for expansion factors, volume equations and table labels. The data sheets supply the tree data.

The system produces tables of volumes by species and diameter class; volume by basal area and species; volumes by species and log grades; ten-year predicted stand and stock tables; tons of pulpwood; basal area and number of trees by species; a statistical summary; and a list of wood-using industries in and surrounding the county in which the sample tract is located. Several of these tables are optional and requested by means of the request form.

This system is an excellent example of good system development practices which make a system easy to modify and transfer from one computer installation to another. A great deal of emphasis has also been placed on tailoring the program for use by field foresters. For example, forms have been kept simple, alphabetic codes can be used for species, results are printed in standard page-sized format for insertion in management plans and reports, and abbreviations are used only where self-explanatory or in common usage. In other words, priority has been given to program usability over maximum computing efficiency. Program documentation is also complete and usable.

The program is limited in that it cannot handle stratified sampling or summarize data over more than one tract. The variety of field forms for different types of cruises also tends to be confusing as well as the method used to denote half-logs in trees. The necessity of transferring field data by hand to a different form for keypunching can also lead to errors in transcription.

Purdue Forest Management Planning System

This is a new version of the Purdue Forest Data Processing Service (Moser, 1976; Rauch and Moser, 1976). It will retain all the desirable features of the present program and, in addition,

will incorporate the following improvements and features: The ability to handle stratified sampling; the use of either Forest Service or Purdue log grades; provision for user-defined class and vigor codes; growth projection through updating the tree list using average growth by size class; simulation of removals by cut-and-leave tally, lower and upper diameter limit cuts, rate-of-value-increase (with or without basal area restriction), tree class cut, vigor class cut, lower or upper dollar limit cut, and species selection; value calculation based on quality index tied to log grade, species, and DBH; calculation of periodic rate of return for the next 10 years; and one standard input form to handle all types of cruises or inventories. The program is presently undergoing field testing.

A much more complex request form is required for this program because of the number of features and options available, but the field data sheet has been greatly simplified. Data can now be punched directly from this form. The program compiles a variety of tabular data in a form suitable for inclusion directly into a forest management plan. In summary, the program has retained all the desirable features of the earlier version and many new and desirable features have been added. The main restriction is the lack of capability to summarize a number of tracts, although a number of tracts can be processed in each run.

Cruise

CRUISE, developed by the University of Wisconsin, is modeled after the Indiana system (Ek, et al, 1973; Ek, 1975). The program utilizes an input format which allows field crews to record tree data sampled in a variety of ways. Standard printouts include stand and stock tables, harvest stock and residual stands, and optional statistical summaries and growth projections. Allowable sampling methods include point sampling, 100% sample, fixed-area plots, and percentage cruises. The program also handles plot slop-over (boundary bias) and missing data. The heading of the tally sheet is used to specify the kind of sample being used, expansion factors, sawlog lengths, definitions, etc. The program would have to be modified to use volume tables instead of equations. A more serious problem may be that the program has not been used on a production basis and may not be completely debugged. Considerable reprogramming would also be necessary to use the program on a computer other than a UNIVAC 1100 series, since conventions peculiar to the UNIVAC FORTRAN V language have been used and the shorter word length of some machines has not been considered.

FINANCIAL ANALYSIS PROGRAMS

A number of programs are available to provide financial investment analysis. The programs range from ones which give the rate of return from a single transaction to those which will handle several problems with complex inputs simultaneously and express the results in several forms, including present net worth, internal rate of return, benefit-cost ratio, present net worth per dollar of initial cost, or annual equivalent income. Among the major programs available are:

- DAMID (Discounting Analysis Model for Investment Decisions) (Gieske and Boster, 1971).
- NCRETURN (Schweitzer, Lundgren and Wambach, 1967).
- SASSY (Goforth and Mills, 1975). This program also incorporates procedures for sensitivity analysis.
- PAR-3 A modification of a computer program developed by Row (1963).
- FINACT (Anon., 1975).
- MULTIPLOY (Row, 1976), which enables the user to simulate both timber and other outputs from forest land management over long time periods and evaluate the financial returns of these management options in terms of income per acre, rate-of-return on investment, long-run average revenues and costs, and required capital expenditures. The system may also be used to develop data for resource allocation models, such as Timber-RAM (Navon, 1971).

I am sure there are many other financial analysis available.

Certainly, with the wide range of programs available, there is no longer any need to perform these tedious calculations by hand if there is a computer available.

RESOURCE ALLOCATION PROGRAMS

Although the concept of resource allocation programs is not new, in the past such programs have been developed primarily for large tracts of land and have tended to concentrate on a single resource, such as timber or recreation (Navon, 1971; Clutter, 1968; Hill, et al, 1974). At present, only one resource allocation program designed for use on relatively small tracts of land is available and, although it still has limitations, it should be emphasized that this is the first attempt at such a program and it is continuing to be developed and improved. This program is the Wildland Resource Allocation Procedure (WRAP) developed by the Tennessee Valley Authority (Hamner, 1975). The objective of this program is to provide a uniform, multiple-use approach to managing wildlands. Although the original idea was to produce a

management plan which could be sent directly to the landowner, it has now been recognized that guidance and interpretation of a forester will continue to be necessary.

The forester and landowner complete a form which gives basic information about the landowner and information used for some computations in the program including age, alternative interest rate, future date when a monetary return is needed, market value of property, and current or expected taxes. The landowner then ranks, on a scale of 0 to 10, eight objectives. Twenty-five additional objectives are checked either yes or no. A tract inventory form, containing information on each tract making up the property must be completed. In addition to identification data, these forms contain information on area, land use, special areas, proximity to water, and water pollution. For both the present and future stands, information on timber stand age, site index, stocking density, volumes of harvestable sawtimber and pulpwood, number of intermediate cuts, interval between cuts, and residual basal areas are recorded. In addition, the forester prescribes management recommendations for the present and future stands. Cruise data must presently be summarized before it is entered on the form, but eventually the program will be able to compile raw cruise data. After the initial ranking of objectives, an additional refinement of the wildlife objectives is necessary before the data can be processed.

The WRAP program attempts to allocate the landowner's holdings based on his ranking of objectives. Certain of these objectives are incompatable with other uses, and land for these uses will be reserved without further consideration. For other uses, the program predicts the maximum and actual amounts of production of various resources that can be expected to be produced from each tract. For a number of harvesting schedules, the program compares the resources which would be produced with the maximum and chooses the alternative which differs least from the maximum when weighted by the landowner's objectives.

The program produces a truly massive volume of output. Depending on the landowner's ranking of objectives and the allocations made by the program, specific management messages will be produced. In addition, information is generated concerning other interests and land management concerns which are not a part of the allocation procedure. Although some of this information is rather cursory, most of it is detailed, including facts and figures and references for further information. In addition, computations of the probable future value of the land and several retirement income strategies can be produced. A long-range prescription (for the next 50 years) is made for timber management on the property, both for optimization of timber only and for all resources. Information and computations are provided on estate planning and the cost of borrowing money. Most of the information is presented clearly, although some items need interpretation or further explanation by a forester, estate planner, banker, or other professional for the landowner to put them into practice.

The program is unique in its ability to provide multiple resource management data. The descriptive text, customized for each landowner, as to the potential of his land and specific suggestions on management, should help the forester to make truly multiple-use management plans. Consideration of the landowner's desires for his land is also good insofar as it helps the forester consider other uses besides timber. Too often, the landowner's needs are not fully explored and taken into consideration. On the other hand, there is also a danger here since the landowner's desires may or may not be what is best for him, the resource, or the land. Most landowners consult with a forester in order to find out how to manage their lands. Thus, foresters should not fall into the trap of using a program such as this as a substitute for professional guidance, interpretation, and recommendations.

The program has a number of technical constraints. Even though many improvements have been and will be made, it is obviously impractical to program all the knowledge and experience of a forester into a computer, no matter how large the program, and care must be taken to avoid the impression that this is what has been done. A further danger is that the program may be used by well-meaning persons who do not know the limitations of the program or disregard these limitations because the program provides a quick and easy way to produce a management plan. Precautions must be taken to see that the program is not used beyond its limitations.

INVENTORY AND ANALYSIS PROGRAMS FOR OTHER RESOURCES

The Illinois Forest Inventory Data Processing System

An integrated system for processing inventory data from timber surveys, wildlife food and habitat surveys, ecological surveys, or combined multiple-use surveys has been developed by Pelz and Thom (1977) for the State of Illinois. The system is based on the Indiana system developed by Moser but has been modified and extended to include these other

resources. Since this system has been described in an earlier paper in this workshop, no further description is needed here.

Other Programs

Most systems for processing data from small ownerships have tended to concentrate on the timber resource and relatively few systems are available for processing other resource data collected on these lands. A search of the U.S. Forest Service's library of computer programs identified the following systems which apply to other resources and might be adapted for use on small ownerships:

A conversational program to calculate and display range production utilization data and grazing capacity estimates. This can be used for both an individual pasture or an entire allotment.

A program for estimating erosion rates from soil types, soil surface characteristics, precipitation, slope, and vegetative cover.

Several programs for computing soil moisture regimes.

A routine for comparing the effects of proposed land use activities on sediment yield.

A program to evaluate wildlife habitat types.

A program to simulate the production of timber and its effect on deer habitat (Myers 1977).

CONCLUSIONS

Development of computer programs for processing data from small ownerships is not as far advanced as for large ownerships, but a number of attractive programs are now available for use by service or consulting foresters.

The timber cruising and inventory programs should be considered by anyone who has a substantial amount of this work. Three of these programs, CRUISE, SURVEY, and the Purdue Forest Data Processing Service, provide most of the features and options that would be desired by many users--they differ mainly in the output tables produced and the ease by which they could be adapted to different areas of the country and to different makes and models of computers. The Purdue Forest Management Planning System, when operational, should prove to be an even more powerful and useful program.

A wide range of general-purpose computer programs for financial analysis are available. Users should find that one of these meets their needs, or could be modified without too much effort.

The resource allocation program, WRAP, has a unique orientation to multiple use management, but foresters who use it should recognize the limitations of the program and use it only where appropriate. The forester should incorporate applicable parts of the results into his management plans, interpreting them and using them according to his best judgment.

Integration of inventories on small ownerships is just beginning. The development of computer programs for processing data on other resources has lagged behind the timber function, as has also been the case with large-scale inventories. Recent developments, such as TVA's WRAP system and the Illinois Forest Inventory Data Processing System, described by Pelz (1978) earlier in this workshop, indicate that there has been substantial thought and progress in this area over the last few years. Future work should provide more and better computer-based systems for the analysis and compilation of other resource data and facilitate the eventual incorporation of these into a common inventory process.

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Timely Resource Information Through Process Modeling: The North Central System Experience[1]

Roland G. Buchman[2]

Abstract.--Forests are complex dynamic systems characterized by multiresources, interacting components, and diverse processes. Characterization of these systems must include the mechanisms of change as well as an inventory of their current state to provide timely resource information.

The North Central Forest Experiment Station has developed a generalized forest growth projection system for representing a complex forest ecosystem. With this system the known initial state of the forest (the inventory) is moved through time based on the underlying processes (the projection system). Special emphasis is placed on birth, growth and death.

Understanding these processes under the wide range of forest conditions encountered in a region and subsequent application of the system set the dimensions of the sampling and recording problems. Consideration must be given to the components of the resource, to continuity, and to processes under diverse forest conditions.

INTRODUCTION

Renewable resource assessment and resource planning, as directed by the Forest and Rangeland Renewable Resources Planning Act of 1974, demand timely national resource information. Resource assessment and planning by State and local public agencies and by large forest industries depend upon up-to-date resource knowledge.

Forests are complex dynamic systems characterized by multiresources, interacting components, and diverse processes. Characterization of these systems must include the mechanisms of change as well as an inventory of their current state to provide timely resource information.

How easy it is to call for comprehensive resource data, data that require several years of intensive field work to assemble. Consider, for example, the timber resource data for the Lake States Region. Even while gathering this information it is aging. The first data collected are already several years old upon completion of the inventory. It appears we shall be forever frustrated if our resource planning and assessment depend upon having "fresh" resource data.

An alternate route for achieving up-to-date resource information consists of updating a prior inventory, adjusting the data to reflect the ongoing changes inherent in a dynamic system. Additional adjustments are required to duplicate the effects of human intervention on the resource.

RENEWAL THROUGH SIMULATION

Inventory data gathered today provide a snapshot of the resource as it is today, information on the momentary state of the resource. It isn't feasible to get a new picture in response to each need for resource information even though our response should be based on timely information. If resource change can be modeled, then the current resource state can be estimated through simulation. This depends upon modeling the processes of change--birth, growth, and death.

The model must pursue the essence of these processes. This embodies more than

[1]Paper presented at the Integrated Inventories of Renewable Natural Resources National Workshop, Tucson, Arizona, Jan. 8-12, 1978.

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just searching out mathematical functions that mimic data; it depends upon understanding these processes and selecting a mathematics that reflects their behavior.

To be understood, these processes must be observed over a broad range of resource conditions; the extremes must not be neglected. With timber, the change processes must be observed over the full range of the forest including mixed stands, pure stands, open stands, overstocked stands, young stands, and decadent stands.

Furthermore, observing the forest and the individual trees only once will not reveal change. Measurements must be spread over time and be of sufficient number to pinpoint the rate and direction of change.

Extensive planning, data gathering, and analysis are involved in developing a model to estimate change. These efforts must be specific to the process being modeled. Clearly, this information cannot be extracted from conventional inventory data.

Some of the necessary information can be obtained from research data. Silvicultural data abound on the important commercial species but are scant for other species. We are short on the detailed and frequent observations of the regenerating forest and of the deteriorating forest, data critical in process characterization.

Our task remains: we must make today's inventory pertinent for the questions of tomorrow. We must plan and conduct the research needed to improve our knowledge of the forest processes even as we synthesize the information presently available.

THE NORTH CENTRAL SYSTEM

The North Central Forest Experiment Station has recognized the need to provide timely information about the current resource and its future development. We have developed a forest growth model and a forest modification model applicable to the conditions encountered in the Lake States, including the full range of forest types, species mixtures, and stand ages, sites, structures, and densities.[3]

[3]The details of the growth model and a portion of the modification model appear in a preliminary report for a public review held in September 1977. Publication of this material is planned for early 1978.

A computerized system has been prepared incorporating these two models into a generalized forest growth projection system (fig. 1). Using this system, a resource manager can update an existing timber inventory data base to estimate the present state of the resource and project its future.

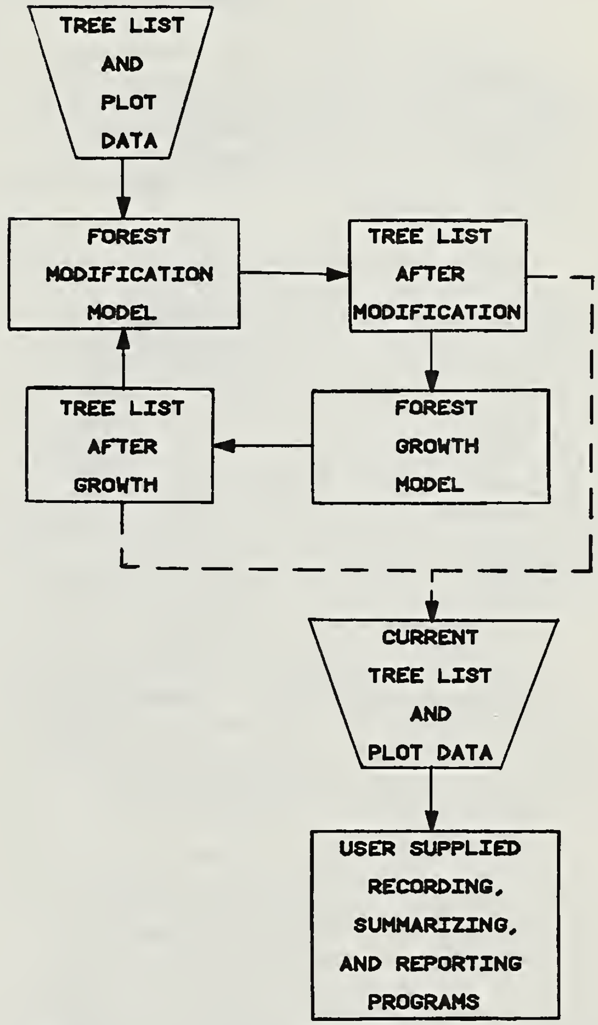

FIGURE 1.—THE NORTH CENTRAL STATION'S GENERALIZED FOREST GROWTH PROJECTION SYSTEM (DASHED LINE INDICATES USER INTERVENTION TO GET TREE AND PLOT DATA AT ANY STAGE OF THE PROCESS).

The system requires information about the forest gathered from the trees on a fraction of an acre within the forest, the forest plot. Detailed forest measurements are accepted and acted upon by the system; an updated set of forest measurements is produced. It accepts and processes the forest conditions and species mixtures found in the Lake States.

Forest growth

The growth model (fig. 2) treats the forest as a set of interacting, dynamic components. The growth of each component is expressed as a function of its potential in the absence of competiton, modified by the competition of trees within the component and from other components.

Forest components are formed by grouping trees according to important characteristics, in particular, species and diameter. This permits utilizing different growth rates and competition effects in forests with mixed species and sizes; a wide range of forest conditions can be modeled. This grouping is done for each plot by the projection system itself, following programmed rules. Forest diversity and amount of growth information dictate the need and ability to form components. We feel there is little to be gained in having more than nine species-size groups or components. Grouping all trees into one class reduces the model to a stand model.

Growth is attributed to each component of the forest in relation to its potential growth and its competition. Each component's growth is then apportioned among the trees included within the component. Each tree's diameter is increased to include its assigned growth.

Potential growth and competition are based on plot data consisting of the site index and age of each important species and the plot's tree list. This list contains the diameter, species, and crown ratio of each tree. It is important to include all live trees that are potential competitor or product trees on this list. These plot data and tree list enter the system as the basis for projection.

What happens when the complete list of individual tree diameters has not been recorded for the plot, as is often the case? For example, an inventory including only merchantable trees, neglecting some potential competitors, is not a complete list. Neither is a plot summary containing only the number of trees and average diameter by species. When we encounter incomplete data we fill out the list, based on the available plot and tree information before it enters the system.

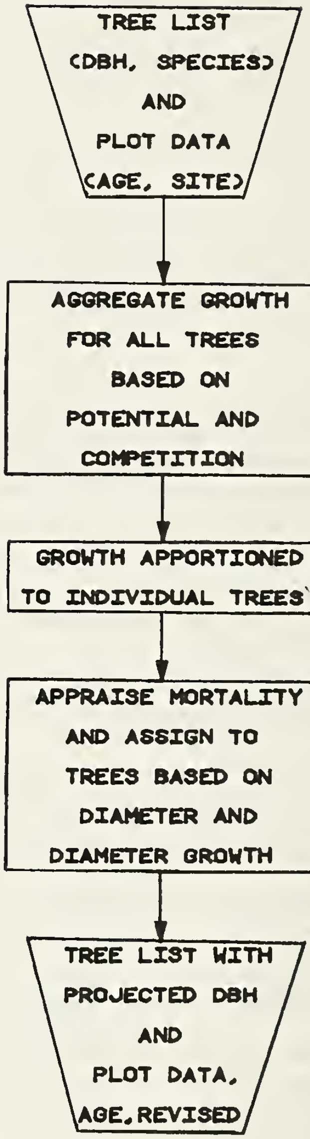

FIGURE 2.—FOREST GROWTH MODEL IN THE NORTH CENTRAL STATION'S GENERALIZED FOREST GROWTH PROJECTION SYSTEM.

Forest growth is completed by determining which trees, if any, should be classified as having died during the growth period. This is done by estimating each tree's probability of dying, given its diameter and diameter growth and selecting "dead" trees in proportion to this probability. Records are kept on each dead tree, although these trees do not enter further growth calculations.

Forest Modification

The modification model is an adjunct to the growth model, providing for tree addition to or deletion from the plot tree list (fig. 3). Timber production is emphasized; any model accepting the tree list and plot characteristics resulting from the forest growth model can be readily substituted.

After of each growth cycle or selected growth cycles, modifications in the forest's composition are considered. Decisions relating to the specific action for a forest are based on species composition, the number of trees on the plot, the diameter and ages of these trees, the plot's density, and other characteristics.

In some cases the silvicultural actions taken to control the composition of the forest are known and specified. Here the criteria for removing trees result in coding individual trees for cut whenever forest modification calls for timber harvest. Trees will usually be removed if the forest is mature or overstocked. Trees may be removed from an understocked forest if they will interfere with the young growth. The decisions depend on the demand for timber.

At other times the criteria for timber harvesting from forests are not known. For example, on a regional or national inventory, the bases for the decisions of the numerous small forest owners are unknown. Yet trees from these holdings show up in the market. Rules for cutting based on the market records are applied to plots; trees selected for cut are so coded.

Provision is made for removing trees from forests regardless of whether the silvicultural actions are known. However, the criteria for determining the plots from which trees will be removed and the trees actually selected will differ.

Each new tree entering the forest during simulation, as a consequence of either human intervention or natural forest processes, is considered for inclusion on the tree list. Those trees likely to become important during

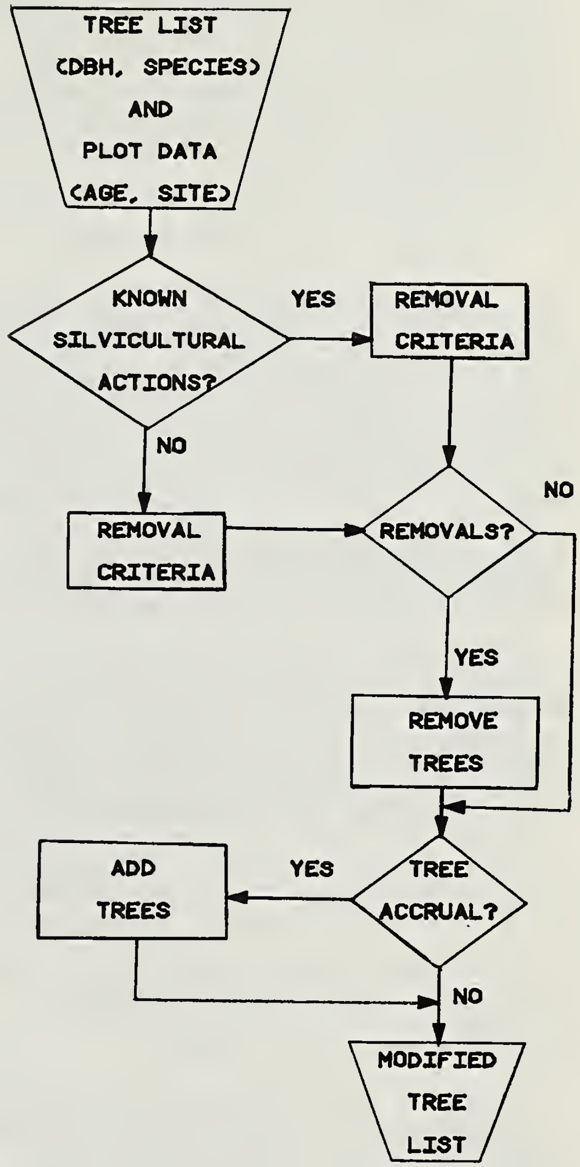

FIGURE 3.--FOREST MODIFICATION MODEL IN THE NORTH CENTRAL STATION'S GENERALIZED FOREST GROWTH PROJECTION SYSTEM.

the term of the projection, either as a competitor for the other trees or as a forest product, are added. This decision is based upon the conditions of the forest, the years remaining in the projection, and the eligible products.

Each tree entering the system retains its identity throughout the simulation; its diameter and status at any time (alive, dead, or cut) reflect the changes it has undergone. The diameter and status of each tree, including those trees added during simulation, and updated plot characteristics are available as output at each stage of the process.

APPLYING THE NORTH CENTRAL SYSTEM

We have updated the plot and tree detail data for Wisconsin Forest Survey Units, producing a current inventory of each plot's characteristics and trees in the format of the original inventory. In addition, we've projected this plot and tree detail data producing an estimated future inventory. These are the equivalent of two new bonafide inventories, available for summary and analysis. They have been utilized in identifying present and future silvicultural needs and in estimating associated treatment costs and treatment impact on timber removals and residual timber volumes.

These demonstrate the two broad uses we envision for our system. One, updating, makes past inventory data current. The update run takes plot tree lists from previous years and grows these trees to the present. History, such as known product removals and general growth conditions, can be accommodated.

The other, projecting, carries inventory data into the future: trees from each plot are grown through the years of the projection.

Both uses can be initiated from plot tree lists originating from either temporary or permanent plots. Tree lists can also be derived, as from a stand table.

Simulated growth, mortality, removals and regeneration from tree lists reflect the changes taking place in the forest. Typically, we stratify the forest on the basis of forest type, tree size and stand density. Tree lists from plots within each stratum provide means for updating and projecting the resource inventory by stratum. The number of plots required varies by forest stratum depending upon the resource variation within the stratum and the accuracy desired.

STATUS OF THE NORTH CENTRAL SYSTEM

Our first concern has been forest growth because we consider it to be the nucleus of a resource evaluation system. Hence, conception of the growth model, begun late in 1974, preceded that of forest modification. Encouraging progress on the growth model stimulated development of a model to intervene in forest processes. Consequently, the two models are not at the same level of refinement.

Forest Growth

Data used in developing the growth proccessor covered the major Lake States' forest tree species and types. The base consisted of permanent growth plot data from 44 different studies including cutting experiments, demonstration woodlots, industrial continuous forest inventories and personal records of forest growth. Included were 1,501 plots having repeated measurements on 92,649 trees for as many as 36 years.

Each of the components in the growth model, including the aggregated growth of all trees based on potential and competition, the allocation of total growth to trees, and the probability of tree death, was developed independently. Growth for the initial tree list from each of the 44 studies was projected and compared with observed growth up to 36 years later. The agreement, based on average tree diameter, trees per acre, and basal area, indicated the components in combination did model growth.

To judge the applicability of the growth model to general Lake States forest conditions, we projected the growth for five data sets not utilized in model development. Three sets were National Forest inventories; two were large research studies. Comparing projected with observed growth for as long as 17 years showed the system doing an acceptable job.

Based on calibration data extending to 36 years and validation data to 17 years, we are satisfied with projection results for most forest types up to 30 or 40 years. We will continue to fine-tune system components to stretch growth projections for a full rotation of perhaps 80 to 120 years.

If you have a set of plots where trees have been measured at least twice and records have been kept by tree, you can run your own validation of our system. A validation projection is an option within our system. Output includes a comparison of actual with projected growth.

Forest Modification

The process of determining, for each plot, if trees will be harvested and the selec-

tion of these trees relates to the condition of the forest, to the total resource, and to the market. Harvest decisions can be based on silvicultural guides expressed in forest conditions, tempered by the total resource and the market.

Silvicultural guides recommended by the Station and/or used by the National Forests in the Lake States are part of our system. These guides, applied over a 20-year projection period to inventory plots from a National Forest, have provided realistic treatment opportunity summaries. The tempering effects of resource or market can be accommodated through modifying critical values such as rotation age and desirable stocking, or through imposing volume harvesting restrictions. Substitute your own guides, if you wish.

Forest harvest decisions can be deduced from the relation of market data to harvest data. Data from several National Forests and from Wisconsin Forest Survey Units, with corresponding market data, have been used to develop rudimentary guides. Further tests and refinements are underway. These deduced guides intervene where the specific silvicultural actions taken are unknown.

Replenishment of the forest has not been forgotten. A model is being formulated now and scheduled for inclusion in 1978 based on Station research, Wisconsin Forest Survey data, and National Forest data. When forest conditions warrant the inclusion of new trees, the system will enter them.

What Next?

Refinement will continue, at least for several more years. Our tests and the experience of users will lead to improvements, perhaps additions and deletions. But there is more to the forest resource than the trees.

The other vegetative components must be considered both as a resource and as an influence on trees and wildlife. Wildlife residing in the forest is itself a resource and it interacts with the vegetative resource. We are exploring this vegetative-wildlife interaction and are developing a model linking deer, moose, and hare to browse, browse to timber yield, and wolf to deer, moose, and hare.

We will continue to emphasize the characterization of the processes underlying the forest resource, our goal being to provide "life" to the conventional inventory. Not content with knowing just the momentary state of the resource, we will continue to develop the means for obtaining timely resource information and estimates of its future from the inventory of yesterday. Although our efforts to date have been concentrated on timber, we recognize there are other important components to the forest and are moving from our narrow path.

Panel VIII — Natural Resource Management Information Systems: Their Role in Today's Decision Environment: Moderator's Comments[1]

B. Bruce Bare[2]

Abstract.--Computerized management information systems for natural resource applications consist of four principal components: (a) a resource data base -- usually spatially structured, (b) an information processing system, (c) a decision analysis system and (d) a decision maker. The function and importance of each of these components is briefly described with particular emphasis placed on geographic or spatially-oriented natural resource information systems. Lastly, three observations concerning the current role of natural resource information systems for aiding decision makers are presented.

INTRODUCTION

Today natural resource managers operate within a dynamic and challenging environment. Not only are they concerned with the dominant problem of allocating a relatively fixed land base to satisfy spiraling demands for a set of competing and often conflicting uses, they must cope with the needs to consider environmental amenities, active participation of concerned citizens, and highly organized pressure groups in land and resource planning. These factors have added new dimensions to the natural resource manager's decision making framework and have stimulated the need for the comprehensive analysis of alternative resource management policies.

The vast amount of data inherently incorporated within such analyses has led to many applications of computer-based management information systems. The impacts of computer-based systems in such an environment lie primarily in the efficiency with which vast amounts of natural resource data can be analyzed and organized into meaningful information. The importance of such a system lies in its facility to allow users to employ data in ways that cannot be precisely anticipated and yet produce information in a form that is easily understood, enhances communication, and leads to improved decision making.

Computer-based management information systems (MIS) became popular in the 1960's as organizations rushed to harness the potential power of the digital computer for assisting in the management of the organization. Although touted as a panacea for decision makers, most applications produced far less than promised. Nevertheless, interest in such systems has not diminished. On the contrary, it has increased dramatically in recent years. Consequently, many natural resource agencies and firms are accelerating their efforts to develop and utilize such systems.

Today we have a distinguished panel of five speakers who will address the role of natural resource management information systems in today's decision environment. I would like to set the stage for the panel by making a few introductory comments and observations related to natural resource MIS.

COMPONENTS OF A MANAGEMENT INFORMATION SYSTEM

A MIS is a complex system composed of a series of interdependent components. Chief among these are: (a) a computerized resource data base, (b) an information processing system, (c) a decision analysis system and (d) a decision maker. The principal function of a MIS is to facilitate the transformation of raw data -- retrieved from a data base -- into

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[1]Paper presented at the SAF Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.

[2]Associate Professor, College of Forest Resources, University of Washington, Seattle, WA 98195.

information which in turn is converted into action through the process of decision making. Information, then, is the knowledge derived from the acquisition, organization and analysis of data. The primary focus of a MIS is related to the management of a system and not the collection and storage of vast quantities of data. To better understand the characteristics of a MIS each of the above components will be briefly described.

Information Processing System

The information processing system provides the facilities necessary to acquire, store, update, retrieve, and display data in a timely and meaningful format. While it is a vital component of any MIS, it alone is not sufficient to guarantee the success of the system. Unfortunately this has not always been recognized by many potential users. In fact, it is probably safe to conclude that one of the leading causes of MIS failure during the past decade has resulted from an over-emphasis of the data base and information processing components relative to the other components of a MIS.

Resource Data Base

The resource data base contains all the data which describes the system being managed. This may consist of: (a) data describing the status or condition of particular units of land or bodies of water, (b) sample plot or other survey data, (c) financial performance data, or (d) other auxilary data such as market surveys or general economic indicators needed by management. Recently, there has been considerable interest in geographic or spatial resource data bases where the locational parameters as well as the attributes describing a specific unit of land or body of water are stored. This type of data base provides the opportunity for a decision maker to: (a) evaluate the impact of alternative decisions, and (b) retrieve and display (i.e., map) various resource values within a location-specific context. Much of the current interest in natural resource MIS centers on spatially-oriented or geographic resource data bases. In fact, several of the speakers on this panel will describe systems which utilize this type of data base.

Spatial Resource Information Systems

The development of a spatially-oriented resource data base and the corresponding information processing system involves four primary tasks:

(1) data acquisition -- collecting, categorizing, and converting source data into a machine-processable form;

(2) data management -- defining the logical data structure of the data base, entering the data into the data base, and maintaining the data base after creation;

(3) data processing -- accessing and manipulating data from the data base, including selective extraction capabilities;

(4) information display -- organizing and formatting information into user-oriented reports and graphic displays (i.e., maps).

Data Acquisition

Data acquisition is concerned with the preparation and conversion of source data into a machine-processable form. Data preparation includes the collection and organization of source data pertinent to the application. The function of data conversion is to transform the recorded data into a machine-processable form. The methods used in converting data to a machine-readable form depends upon several factors including the source and nature of the data, the volume of the data, the accuracy requirements, and the time and cost constraints involved. Automated methods of data acquisition have greatly increased our ability to deal with high degrees of resolution in characterizing an area. Resolution ultimately deals with two major concerns: (1) to what level of detail must an area's characterisitics be described to effectively represent the area for a particular application, and (2) how many dollars must be expended in order to obtain that level of detail? Resolution constraints imply a balance between high degrees of detail and the costs associated with the level of detail.

Two general approaches are commonly used for constructing computer-based spatially-oriented resource data bases: polygon and grid (cell) systems.

Polygon systems.--Polygon systems are characterized by groups of areas of irregular size and shape which permit considerable flexibility in terms of spatial resolution and accommodate the use of automatic digitizing equipment in the conversion of source data from maps to computer data files. Typically, a separate overlay or profile is constructed for each attribute included in the information system. Such data stratification is accomplished prior to data storage, thus necessitating multiple accesses to retrieve a complete description of a specified spatial extent. This type of system, however, provides the capability to obtain high resolution reports and graphical displays of areal characteristics.

Grid systems.--Grid systems are generally characterized as a grid of fixed or variable

sized rectangular cells, or both. In effect a grid cell is a special case of a polygon -- i.e., a regular polygon (rectangle) -- where the inherent characteristics of rectangles can be used to simplify the software required to manipulate the data files. The boundaries of the cells are fixed, and the set of attributes representing the characteristics of the area circumscribed by the cell can be referenced in entirety by referencing the cell, thus allowing the complete description of a specified area to be obtained by one data base access.

When involved in developing such a system one should carefully consider which approach will provide the most effective and efficient decision making tool. The high-resolution characteristics inherent in polygon systems should be compared with the costs associated with maintaining and manipulating the data files. These features should be weighed against the advantages of access and updating of grid system files with the attendant loss of resolution involved. For systems where the primary requirements are to support broad-scale planning or to provide an analytical decision making tool for assessing the impact of alternative policies, or both, the grid system should be considered. If extremely high resolution is required for reports and graphical displays, however, then one should consider a polygon system. There are hybrid systems that incorporate advantages of both system approaches, including a polygon-type system for data acquisition and a grid-type system for data processing.

Data Management

Briefly data management consists of: data definition, entry and maintenance. This consists of a whole series of steps which essentially transform the data from the data acquisition files to the resource data base. It also involves editing and updating of the data base once created.

Data Processing and Information Display

Data processing refers to the use of the system and is primarily concerned with the user's ability to interrogate the data base, extract selected data partitions, and manipulate the data according to some specified procedures. In a spatially-oriented resource information system, data base interrogation necessarily includes two primary forms of extraction -- areal and constraint. Areal extraction allows the user to selectively extract data according to locational characteristics, so that areas can be described and information about those particular areas can be obtained. Constraint extraction refers to the capability of extracting areas that satisfy a given set of constraint conditions imposed on the characteristic set describing the land base. This allows the user to obtain all areas that satisfy a specified set of constraints.

Manipulation of data involves both summarization and analysis of information. Summarization is perhaps the most common means of obtaining information from data. This type of manipulation yields descriptive information about the areas of concern. For each application there are certain other analytical processes that are important in order to obtain useful information for planning. An information system should include the capability to allow the user to interface specific application-oriented processing modules with the system, using the facilities of the system to produce intermediate files which can then be input to specific decision analysis programs. These latter programs provide direct input into the decision making process. Finally, information display involves the presentation of summary and other graphical reports such as maps to the user.

Decision Analysis System

The decision analysis system consists of those application programs which are used to predict the probable consequences of alternative management strategies. The information processing system provides the needed input for these programs. Various analytical procedures such as mathematical programming, computer simulation, and financial analysis are used in this regard. When tied to a spatially-oriented resource data base, these procedures facilitate the prediction of location-specific impacts of future strategies. More generally, however, resource data are aggregated into management units before being analyzed by the decision analysis system. Probable impacts of alternative strategies are ultimately summarized and passed on to the decision maker for final action.

GENERAL OBSERVATIONS

With this brief introduction to natural resource MIS let me close my remarks with a few general observations. First, I hope it is now clear that to be effective a MIS must provide some capability for interpretation of the data to aid in the decision making process. Thus, the system must ensure that the data are accurate, timely, in the right place, in the right form, and in a language that conveys a clear meaning to assist the decision maker in achieving his objectives. The function of a MIS is to provide information and communication that most effectively aids the planning unit to operate, control and manage its resources in a manner that best fulfills its objective. The

proper role of a natural resource MIS is not to collect and store vast quantities of data just because it seems like a good thing to do.

My second observation -- somewhat philosophical in nature -- relates to the frantic pace with which new computer software and hardware developments burst upon the unsuspecting resource decision maker. I feel that during the past decade these developments have greatly exceeded our capability to effectively incorporate such technology into the decision making process. For example, new data acquisition systems, automatic digitizers and scanners, graphics display units, micro-processors, mini-computers, generalized data base management systems, etc. continue to pour forth at an ever-increasing pace. However, the ability to assimilate and incorporate such technology to produce better decisions leading to improved performance continues to move at a much slower pace.

The implications of this are twofold. First, organizations which attempt to keep pace by incorporating new technology are constantly in a state of flux. Not only is this very expensive but it also tends to disrupt the normal flow of information, encourages morale problems and may lead to reduced levels of performance. However, those organizations which maintain the status quo soon find that their systems are woefully outdated. Then when the ultimate decision to upgrade is made, the organization suffers through a dramatic change. Usually new personnel are brought in to help (or replace) those accustomed to the old system. Neither of the above scenarios is desirable but examples of organizations following these two strategies are not hard to identify. Luckily, however, most organizations follow more of a "middle-of-the-road" policy than either of the two extreme cases just presented.

My final observation takes root in the increased environmental awareness fostered during this decade. Unquestionably, this has stimulated a renewed scientific effort to better understand the natural resource systems we depend upon for our survival. Emanating from this has been a massive increase in efforts to collect, store and display data describing almost every conceivable natural resource system in the U.S. Many of these efforts are directed at the development of spatial resource data bases. Because of the volumes of data presently being collected through these increased inventory efforts, many organizations are turning to computerized MIS. However, I am afraid that most of these organizations will discover that even computerized systems will not solve their problems. The reason is simple; a MIS is not a repository for massive volumes of data. Instead it is a system for organizing and presenting information needed by decision makers to guide the organization to its stated goals. The collection and storage of vast quantities of spatial resource information will not by itself improve our understanding or management of any natural resource system. It will, however, fulfill the objective of cataloging and describing the present status of the particular system. Thus, I feel that a lot of the current efforts to develop natural resource MIS place undue emphasis on data collection, storage, retrieval and display and not enough emphasis on the decision analysis system and/or the decision maker.

In closing, I would like to interject a somewhat more optimistic comment. I think that we have made great progress during the past decade in coping with the complex problems associated with the development and use of computerized natural resource MIS. Great progress has been made and more will undoubtedly occur in the next few years. However, I feel that we must keep all four components of a MIS in proper prespective if we are to develop effective and efficient systems that will lead to improved managerial performance.

Computer Mapping Systems for Integrated Resource Inventories[1]

Elliot L. Amidon[2]

Abstract.--Computer mapping systems can provide integrated, spatial resource information useful in wildland management. Methods to solve the major technical problem of data capture are shifting from manual to automatic. Minicomputers are expected to lower editing costs, but larger computers will still be necessary for complex analyses in the immediate future.

INTRODUCTION

Foresters have been collecting spatial information from inventory maps and aerial photographs for many decades. Since the late 1960's, numerous attempts have been made automate some of the most tedious tasks in the collection process. The various assemblies of hardware and software have been misnamed "computer mapping systems". This is a misnomer because tabulations of measurements are the major product, while the usual graphic output is not intended to be cartographically pleasing. A better designation is "geographic information system," but that term implies a process of greater scope than exists in most systems today.

Computer mapping systems, regardless of the name, are widely used to provide integrated, spatial resource information to wildland managers. The use is often indirect, with output from the graphic process becoming input to other computerized aids to decisionmaking, such as linear programming.

This paper takes the end uses of these systems as given and examines the means to those ends.

What can be said about the state of the computer mapping art after 10 to 15 years of research and development? Dot grids have been used for a generation to estimate sample strata areas for wildland inventories. Have they disappeared from use? Not only is this completely manual tool still widely used, but current research reflects continued interest in its development (Bonnor 1975).

Under certain circumstances, manual procedures are competitive with automated systems. An exhaustive benchmark study showed that manual methods may be less costly if the number of data manipulations is limited. The same study showed that as repetitive manipulations increase, automated methods are preferable on the basis of cost, man-hour requirements, or both (Schwarzbart and others 1976). Although there is more to computer mapping than just computing acreages, area determination is indeed a major product. It is reasonable to expect a computer-based system to be competitive with manual methods for major, routine tasks.

The declining cost of electronics relative to labor should diminish the use of manual methods for computing areas. The real question then is one of selecting appropriate, highly automated computer mapping systems for acquiring integrated resource inventory data. The answers are not simple because they hinge on solutions to problems of data capture, storage, retrieval, and renewal.

GRAPHIC DATA RECORDING

The transformation of map information in graphic form to digital data for computer manipulation is the major expense of most computer mapping systems. Besides being expensive, the process is subject to uncertainty because map data editing is itself an error-prone process. However, even large volumes of data can be processed--given sufficient investment. Data correction, in fact, presents investment alternatives to be weighed against the scale and complexity of the application at hand.

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In addition to volume, source map characteristics will affect strongly the unit cost of data transformation. Either color-coding or a welter of detail can make a map difficult to copy and even harder to trace. The mix of point, line, or areal graphics will dictate the best means of data capture. Many urban applications emphasize point data, such as street addresses, while soil or vegetation areas are of primary interest to wildland managers. Transportation networks are the main source of lineal data in forest maps.

Graphic input data reduction simply has not advanced to the point where it does not matter how even a simple map is drawn. Even if a map contains only areal information, line density and type--solid or dashed--will markedly affect the cost of data capture.

The first computer mapping systems had all-manual, or pencil-and-paper recording. Gradually hand-guided digitizing devices became available to record coordinates on tape, either paper or magnetic. Automatic digitizing machines have been developed, but require the greatest initial investment among the three data-recording methods.

Hand Coding

Hand coding is the process of assigning an interpretive label to each cell of an arbitrary grid. It was originally devised to utilize a line printer as a graphic device. Each cell of the grid corresponds to one or more print positions on the character chain. A grid of rectangular cells, with sides equal to the print column and line spacings, is laid over the source map and each cell labelled. When printed, the output will be undistorted and match the input map data. Input grids with square cells are also often printed, but it produces a distorted map--usually with an exaggerated length.

The grid cell approach has numerous advantages. A matrix system facilitates data manipulation. Specific codes in a layer can be displayed with the unwanted ones blanked or "sieved" out. Coded cells can be counted, sieved, overlaid, stored, and updated with straightforward algorithms. An individual printer display is essentially unlimited in size since each cell is independent.

Complex applications in spatial analysis are simplified by a rigid grid or matrix structure. A notable example is the computation of slope and aspect for a cell based on the elevations of its neighbors (Sharpnack and Akin 1969). Another is the computation of intervisibility between two points on a terrain surface (Amidon and Elsner 1968). A system (VIEWIT) with many options for analyzing terrain has evolved from line-of-sight or intervisibility problems (Travis and others 1975).

Grid cell systems also have drawbacks. They lack flexibility. As resolution becomes coarser, more characters (longer labels) must be accommodated. One compromise is a pair of characters per cell, allowing with 48 FORTRAN characters about 2,000 distinct labels.

Another limitation of grid cell systems is that small changes in map scale are clearly impractical. The smallest scale increment is a doubling, such as from a two-character cell to one with four times that area. Reducing map scale is a more complex task than enlargement. Generalization is often needed to remove detail in excess of needs for regional planning. The label of each cell must be reassigned to one of a higher level of generalization. The data coalesce into new patterns at an effectively smaller scale, creating blurring of individual details. Generalization is attained at the expense of introduced error with respect to individual cells. The data are, however, still sufficiently accurate for broad, regional planning (Nichols 1975).

Hand Digitizing

The tedium and cost of completely manual collection of map data have spurred hardware development. The simplest digitizer consists of a cursor moved by hand, and a means of recording its position in two dimensions. Mechanical linkages are being replaced by electronics with the X-Y position of the cursor detected by magnetism, sound, or optical sensors. A versatile digitizer with magnetic tape output costs about $18,000.

Manual digitizers have several advantages over the pencil-and-paper approach. Shaded or annotated maps can be digitized at a rate limited mainly by the operator's pattern-recognition ability. Resolution can be finer than with manual encoding so that polygon boundaries can be recorded directly. Resolutions of 0.001 inch are available, and perhaps desirable for automated cartography, but 0.01 inch is sufficient for typical forest maps.

Manual digitizers are simple to operate and widely used for point and line recording. Very different approaches have evolved to minimize errors. The ability to playback immediately after recording each small piece of data has been found preferable to correcting many errors at long intervals.

Of the few operational systems based on the manual digitizer, one of the oldest and best known is the Map/Model system of the University of Oregon (Arms 1970). It is intended for urban and regional analysis as well as wildland graphics. This computerized system includes extensive editing, overlay and updating facilities.

An ambitious project based on manual digitizing is FRIS, a Swedish Geographic Information System. Every parcel can be digitized and cross-referenced with detailed census data. Forest firms will have access to a central real estate data bank in order to, say, locate a plant optimally with respect to both raw materials and markets (Alfredsson and others 1970).

Automated Data Collection

A major modification of hand digitizing is optical line following. Using a computer interactively with a screen, the operator "locks" onto a line and follows it while recording coordinates. At each impasse, which is generally caused by a deadend or branch, the operator intervenes to decide the next step. The hardware is several times more expensive than for a dependable digitizer. Furthermore, an operator is still required. This approach was used in the Natural Information System developed for the U.S. Bureau of Indian Affairs and U.S. Bureau of Land Management (Boeing Computer Services, Inc. 1972). Various problems resulted in the eventual substitution of manual digitizers for the optical line follower.

The latest development in the series of steps to automate computer mapping data collection is automatic scanning. A pioneering effort is the drum scanner built for the Canada Geographic Information System (CGIS). The drum accepts full-size map sheets and digitizes lineal data while manual digitizers record names, or labels, for areas, points and lines. The substantial investment in the scanner is to be amortized over 20,000 specially prepared maps of agriculture and forest land (Tomlinson 1967, 1972).

Developments in military and space technology have favored the automatic scanning approach. Scanners were designed for U.S. Air Force meteorological applications having both digitizing and plotting capabilities with film as the storage medium (Diello 1970).

The Wildland Resource Information System (WRIS), developed at the Pacific Southwest Forest and Range Experiment Station, has spanned the use of two types of scanning microdensitometers. The first, a flat bed scanner, made parallel passes across a map negative recording densities. The scanner had many options but a typical million point scan required 10 hours. Our 2-year-old drum scanner accomplishes in minutes the digitizing that previously required hours. The second type of microdensitometer, a drum type, is less expensive, ranging from about $40,000 to $60,000 depending on particular features selected. It generally offers fewer aperture and spacing alternatives than flatbed scanners (Russell and others 1975).

We prefer automatic scanning to the error-prone and tedious process of hand digitizing. But it is most beneficial when the production of new maps can be modified to take full advantage of the scanning process. Most older, colored, or annotated maps will have to be traced before raster scanning is feasible.

DATA STORAGE AND RENEWAL

For management planning, the national forests are inventoried at least every 10 years. Although the inventory data can be digitized and maintained for 10 years, the best method is uncertain. Magnetic tape is in wide use for both active files and as a low-cost, longer-term storage medium. The rate at which magnetized data deteriorate is generally unknown, but is affected by wear and the storage environment. As a general rule, we rewrite tapes after 2 years. As another precaution, the tapes should be duplicated and stored at a separate location.

Really long-term or archival storage will probably continue in graphic rather than magnetic form. For long-term storage, either the original source map or a photocopy of it can be kept. If new inventory maps are drawn in a form suitable for automatic scanning, then two advantages accrue. Not only is the cost of digitizing reduced, but less storage space is needed. We have stored 15 California national forest inventory maps, originally at a scale of 4 inches per mile, on a single 4- by 6-inch microfiche (Amidon and Dye 1976). Simultaneously, inexpensive diazo copies can be distributed for office or field use.

Arbitrary Grids

Rectangular, fixed grids with cell dimensions proportional to print character spacings are the oldest, simplest form of map data storage. Cell tags or labels may be characters or gray density levels. Boundaries are shown implicitly by changes in labels. A two-character cell can have 2,304 or 4,096 labels with 48 or 64 alphanumeric symbols on a print chain.

Some major, single and multiple overlay tasks have involved both large numbers of cells and expansive areas. A New York State inventory used aerial photographs to estimate land uses by computing the percentage falling within each square-kilometer cell. The single layer contained 140,000 cells spread over a thousand maps (Swanson 1969). A comparable land use planning inventory in Canada covered 10,000 square miles with square-mile cells (Thornburn and others 1973).

Two well-known systems using uniform grids for storage are SYMAP and GRID, both developed by the Harvard Laboratory for Computer Graphics (Harvard University 1973). Census as well as general land-use planning data are displayed as gray densities by overprinting characters on a line printer.

The Map Information and Display System (MIADS), also developed at the Pacific Southwest Forest and Range Experiment Station, has seen wide use since 1966 for river basin planning and soil data tabulation (Amidon 1966). A COBOL version developed by the U. S. Soil Conservation Service allows for almost 4,000 codes using an extended character set.

Data collection with a uniform grid requires a method to ensure registration from one layer to the next. Consistency requires a master boundary to be copied onto each coding sheet. Otherwise, borderline decisions on successive layers may give nonsensical results, such as land in one layer falling on water in another.

The space needed to store grid cells can be reduced by data compression methods. One such scheme uses run length coding to achieve substantial storage savings (Amidon and Akin 1971). Despite such aids, encoding, storing, and retrieving several million grid cells is a tedious undertaking. The labor involved may help explain why data base updating is rarely mentioned in the literature.

Polygon Boundaries

A polygon system stores labels, in the same way a grid system does, but in addition keeps explicit boundaries. For each label there is a string of x, y boundary coordinates. Clearly polygon systems inherently contain more information than grid systems. This fact tends to be overlooked in benchmark tests or other comparisons, in which the main focus is on graphic output differences.

Polygon systems offer flexibility in the exactness with which original map boundaries are copied. Diverse thinning rules have been devised to discard boundary coordinates that are superfluous for reproducing a line within a selected tolerance. Depending on the coordinate system, maps of different scales can be overlaid or otherwise manipulated. Consequently, maps having sparse information like administrative boundaries can be drawn at a much smaller scale than timber-type maps. Just being able to manipulate scale is a most effective means of reducing storage.

Automatic digitizing is highly desirable in order to take full advantage of the polygon data structure. Raster scanning requires new or copied maps drawn with a few, simple rules to minimize subsequent costs. An important rule is that polygon boundaries must be at least twice as thick as the scanning raster diameter and that any ink skips will cause later editing work. All lines must join others, including the map border. This rule disallows polygon nesting, as illustrated by the occurrence of an island in a lake. Polygons in the same plane must not overlap each other, and unlabelled polygons are not allowed. Deviations are detected by editing routines which have evolved to cover most possibilities over the years.

The cartographic requirements are loose--some variation in ink line widths and qualities can be achieved by varying films and degree of reduction. An unusually intricate map can be scanned with an increase in precision by increasing the number of densities recorded. The finer resolution will reduce the number of lines, which nearly touch on the map, from being bridged by the aperture, thereby reducing manual editing, but increasing computing cost.

We find it simply a matter of paying sufficient attention to detail at the map compilation stage to ensure subsequent low-cost editing of the polygon data. Careless map preparation can double or triple processing cost. Some errors are fairly obvious, such as multiple or inconsistent labels for a polygon. The cause may not be obvious. Redundant labelling may actually be due to a line missing which would have subdivided the polygon. A more subtle problem is the creation of spurious small polygons, called "slivers". The fragments can be caused by map registration problems or by repeatedly outlining corresponding boundaries on different map layers. Some small polygons are created naturally by overlaying maps but can be removed automatically according to rules specified by the user.

Although we have had extensive experience with storage and retrieval of polygonal data, updating is potentially a complex procedure. Currently, the procedure for renewal is essentially indistinguishable from editing raw data

initially. Although it is technically feasible to update map data, each user will have to decide whether it is better to keep track of the changes over time or start anew.

DATA MANIPULATION AND DISPLAY

Automated cartography and computer mapping share the common problem of capturing map input data economically. The two differ markedly in graphic emphasis. Systems for automated map compilation focus on such problems as the placement of labels and charges in scale. Computer mapping systems place less emphasis on display aesthetics and more on spatial data analysis. A major system product is likely to be a tabulation which is only complemented by a maplike representation.

Measurement and Logical Operations

The dominant manipulatory option available in virtually all computer mapping systems is area measurement. Polygon perimeter usually accompanies area along with an identifier. The label may be attached to a point within the polygon, which is acquired during digitizing, or a computed location, such as a centroid. Other measurements include point counts and line lengths, useful for editing as well as spatial data analysis.

Two types of logical operations commonly available in grid or polygon systems are called overlaying and sieving. The intersections or unions created by overlaying can be successively combined with additional maps of the same area. Characteristics selected in data can be sieved from all others. The items screened may be relabelled before being tabulated or displayed. These two logical operations are simpler using arbitrary grids than polygons.

Other manipulatory options which apply more to single layers are the generation of bands along highways or streamside buffer zones; creation of a circle or other geometric figure about a point such as a mill site; and the computation of perspective views, slopes, aspects, and visibility between points.

Graphic Output

The earliest computer mapping systems relied on the line printer for graphic output because it was so widely available. The most recent fixed grid systems still use the line printer, and even for polygon systems it is a fast, inexpensive device for data editing. Several fixed grid systems list repeatedly on the same output line (overprinting) producing about 8 to 20 shades of gray. Data encoding, editing, and statistical display costs about one-half as much that in more automated systems with line output. In some urban and land-use applications, statistics are shown for administrative areas, such as census districts or counties as gray levels. In this case symbols are designed for the double purpose of providing a gray density when viewed at a distance and a label, which when viewed closely, can be looked up in a legend.

A flexible alternative to a line printer is a printer/plotter. Like a typewriter, it mechanically prints one character per stroke against a bidirectional platen, and this mode is useful as a general purpose terminal. As a plotter, the major difference is that the positioning resolution becomes four to five times greater. Curved lines can be drawn, for example, by overlapping periods. This feature gives the ability to intersperse upper- and lower-case text with figures. Not only line plot graphics but also gray scales can be produced. It costs only about four times as much as an office typewriter, but at 35 to 45 characters per second it is most suitable for low-volume output.

In addition, we use a conventional, high-speed, incremental plotter with two or three colors for final output. It is appropriate for most display purposes but too expensive to be widely available. Electrostatic printing and plotting on film are also useful display devices with a high setup cost.

CURRENT RESEARCH

Our research is shifting from reliance on batch processing on medium-size computer to a stand-alone, minicomputer installation. This trend began with the acquisition of a drum scanner which included a process control computer and tape drive. It enabled us to scan a source map negative repeatedly until a program determined the best density threshold for separating lines from background. Next, we added more memory and a demountable disk pack, to form a 32-k, 16-bit word minicomputer. Additional peripherals are a printer/plotter, and two CRT's, one specialized for graphic output and another terminal for text.

We expect our scanner-minicomputer configuration to greatly lower the cost of data capture. It is expected to perform such operations on the scanner density output as editing, thinning, data compression, and tape output formatting. These steps alone should reduce the cost of data acquisition by one-third in the near future.

Greater cost reductions are impeded by dependency on medium-size computers for logical

operations such as sieving and overlaying. Valuable, general-purpose, plotting, analytical, and statistical programs available at computer centers mitigate against the decentralization generally offered by minicomputers. A key consideration is the use of film output. Any use of microfiches narrows still further the choice of computing utility. In summary, our research and development effort will place heavy reliance on minicomputers, but is unlikely to eliminate access to large computer centers for specialized services.

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Timber-Pak — A Second Generation Forest Management Information System[1]

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Abstract.--TIMBER-PAK is a new forest management information system. It is a polygonal disk-stored system with a data definition method and a query language. Design and use features are described. Graphical examples of digitizing, updating, slope class generation and querying are provided.

INTRODUCTION

Perhaps it would have been more appropriate if the title of this paper ended with a question mark. On the surface it may seem as if we are adding yet another system to a series of already existing or planned natural resource information systems such as NRIS (Raytheon Co., 1973), WRIS (Russell, Sharpnack, and Amidon, 1975), FRIS (Cassell, 1976), with only the non-acronym name of TIMBER-PAK being somewhat different, reflecting its anticipated use for timberland management rather than natural, wildland, or forest resources in general.

Is the title therefore justified? We think so, although our opinion is naturally biased. On the other hand, it might just be possible that our system is sufficiently new and unique in its capabilities and therefore deserves the title of "second generation." We realize, however, that a direct comparison with a first generation system is implied, and that such a comparison may be unfair, since the utility of each depends strongly on the context in which it is used. The reader must judge for himself.

TIMBER-PAK has been designed to aid the forest manager who must make decisions at a direct forest management level. He may use the system to develop harvest plans, keep track of these plans, cope with restrictive legislation, evaluate the impact of such legislation, locate areas for silvicultural treatment, develop alternative logging plans in relation to cost and taxes, etc.

In doing so, he would have direct access to the system either through a terminal or by having his own stand-alone hardware. He would make queries, enter and update maps, and generate reports in an interactive or semi-interactive mode.

In the remainder of this paper, we will describe what the current batch mode version of the system is like. In the first part we will outline the most important design features, and in the second part we will demonstrate the major use features with the aid of examples generated with the system.

DESIGN FEATURES

TIMBER-PAK is a Geographic Information System (GIS), and like other systems, it has a mapping capability. More generally, however, one can look at it as a Data Base Management System (DBMS) with a mapping capability or as a mapping system with a DBMS. From these points of view it seems as if we are breaking some new ground, because the relationship between geographic information systems and data based management systems has not been well explored (Marble, 1977).

We realize, of course, that the current DBMS capabilities of our system are not to be compared to those of, say, a System 2000 (MRI Systems Corp., n.d.) although such features as a query language, a data definition method, and data base protection are indeed provided.

In the following we will first summarize TIMBER-PAK's mapping features. Then, since a DBMS usually has a data management and a query part, and TIMBER-PAK is not an exception, we will discuss its data management and query design features.

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[1]Paper presented at the Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.

[2]The authors are respectively Senior Scientist, Director, and Staff Scientist, Forestry Division, Earth Satellite Corp., Berkeley, Calif.

Mapping

TIMBER-PAK is a Vector Format System

In a vector format, map features are stored as coordinates of lines, polygons, or points. We selected this approach after examining the resolution, storage, and interpretability requirements of the cell and vector formats. It seemed that for the level of detail required for local forest management, a cell system just would not provide the resolution to adequately represent features such as stream bottoms and roads.

Whole Polygons are Stored

Also, we elected to store entire polygons rather than line segments or chains. The rational was that the polygons, as such, are used with such frequency, that the constant reconstruction from line segments is not warranted. The consequence is that internal boundaries are stored twice. In some systems in which these boundaries are digitized twice, they tend to weave in and out (Dangermond, 1971). In TIMBER-PAK, however, common boundaries are digitized only once but stored twice as a result of a new digitizing method. Hence, common boundaries are identical.

Resource Units and Layers

In addition to polygons, linear and point features (roads, streams, drainage structures, bridges, etc.) may also be stored. We called these basic entities to be stored and manipulated within the system resource units (RU's). The spatial type of an RU was defined as the polygon, line, or point attribute. A layer was then defined as a collection of non-overlapping RU's with identical spatial types and with similar descriptive attributes. Examples of layers are a covertype layer, a stream layer, and a soil layer. Overlapping and different types of polygons, such as political entities (counties, school districts, fire districts), cannot be combined in a layer; the overlap must be removed by taking the intersection. Examples of RU's are covertypes, road segments, contour lines, bridges, and ridge lines.

With the concept of a layer established, we could then distinguish two types of layers: primary and secondary. Primary layers are the ones originally entered into the system; secondary layers are derived from the primary ones by overlaying within the computer.

RU's are Indexed to Control Units

To provide an efficient storage and retrieval system, the RU's had to be indexed to geographical windows. We therefore defined a control layer as a layer of control RU's whose polygons are these windows. The non-control RU was then restricted to be wholly contained within the control RU, which itself is not limited to a rectangular, or any other shape, but may be an irregular unit even with islands if desired.

The control RU is of further importance; (1) it must contain enough map detail to make a display unit worthwhile but not too much for someone to edit the unit without introducing new errors, (2) it must facilitate programming by allowing variables related to the unit to be stored in core memory (for instance, it puts an upper bound on the size of the polygons that may be created), and (3) it must be a natural unit for display and use in forest management.

For western forest management the GLO landsection seemed to fit the bill because it provides an ideal level of detail at the frequently used map scale of 1/12000. Also, at this scale it fits neatly on an 8½ x 11 in. page so that plotted output can be provided by an inexpensive 12 inch plotter.

New Overlay Processor

Throughout the system there are many tasks in which polygons are manipulated in some way. One of the strengths of TIMBER-PAK, in our view, is that all of these tasks are performed by one central polygon processing package: the overlay processor. Because this package is at the core of the system, it provides it with a great amount of logical integrity and reliability.

Because of an entirely new polygon handling method, we were able to achieve a degree of flexibility which allows us to use the overlay processor to: (1) form polygons from digitized lines, thereby removing double boundaries and eliminating editing problems, (2) perform simultaneous Boolean operations (mixed sequences of AND's, OR's, and NOT's) between and within different polygon layers, (3) assist in generating slope and aspect class maps, (4) assist in computing variable polygon label locations, (5) assist in generating "zones" around linear features, and (6) perform windowing and "cookie-cutter" operations.

In all these procedures, islands are handled in a completely general way, eliminating any need

for lollypop sticks or polygon dividers. Clockwise or counter-clockwise digitizing conventions need not be observed.

Data Management

Each RU has a Spatial and Descriptive Record

For each RU two types of records are stored, a spatial and a descriptive record. The spatial record contains the polygon, line, or point coordinates as well as line length and polygon area; the descriptive record contains all the RU attribute data in packed form. Each record has a unique key by which it can be located in the data base or workfile.

Data Access Method is Based on Multi-way Tree

Spatial and descriptive records are organized in a multi-way tree structure called a B tree. This structure has become in increasing use for the management of large disk-stored data bases (McCreight, 1977). It is a variation of the index sequential access method and allows random and sequential access of the data with a guaranteed "worst case" efficiency. No specially scheduled data base maintenance of any sort is required. The data base automatically grows and shrinks as data are inserted or deleted, forming a new root when necessary.

System has Separate Workfile

A system like TIMBER-PAK must not only have a storage method for permanent data such as primary layers, but a place must be found also for intermediate results and secondary layers. This problem was solved by creating a "workfile" which has the identical access method as the data base but a different internal arrangement of spatial and descriptive records. In the workfile, the records are organized by transaction and by the processing stage to which they pertain.

Primary layers are retrieved from the data base and inserted into the workfile for the geographic area of interest at the beginning of a query or update. They are transferred from the workfile to the data base in the case of data entry or data base update.

Since the workfile expands in the same way as the data base, one may keep half finished transactions and secondary layers as long as necessary. If certain descriptive data are not immediately available, the transaction requiring these data may be kept pending until they are. Similarly, one may generate secondary layers and preserve them for future use as long as desired.

Attribute Data are Packed into Descriptive Records

All kinds of attribute data may be stored with each RU. All items, such as character strings, dates, three-dimensional tables (even with unequal row and column lengths), are packed tightly into the descriptive record to preserve storage space.

The structure of the record is defined by a so called "packing table." This table is made at the time when the layers in the system are defined, or when a change in record structure is required. Multiple record structures within the same layer may co-exist, as each table relates to a unique record version.

Each data table, character string, integer, floating point number, etc. is given a data item name by which the item may be retrieved. The names are then read by a packing table compiler, together with additional data definitions such as data types, number of bits occupied, output formats, editing ranges, etc. The computer then constructs the packing table which constitutes the formal definition of the record structure and is subsequently used to retrieve any data items.

Querying

Most data base systems have a query capability by which data item values can be retrieved according to user's specified criteria. These are mostly in the form of Boolean statements containing operators such as AND, OR, NOT, EQ, NE, etc. For example, PRINT EMPLOYEE NAME, WHERE SKILL EQ WELDER, OR SKILL EQ RIGGER (MRI Systems Corp., n.d.). Similar statements can be used to make queries in TIMBER-PAK with a special, easy to use English-like query language.

However, in the context of a polygonal geographic information system, the Boolean operators have a much deeper significance. For instance, requesting those RU's which have both forest type C and soil series code 812/814 requires first that we find all stands with forest type C and then all soil units with soil series 812/814 (a filtering of the layers). Then we must overlay the filtered layers to map completely new units where the required conditions are satisfied.

Thus the Boolean operators in TIMBER-PAK's query language signify that spatial retrieval and combination operations are in order. Two types exist: filtering and overlaying. Filtering refers to the selection process <u>within</u> layers and overlaying refers to a process <u>between</u> layers.

Because whole polygons are stored, filtering is merely a matter of selecting or rejecting RU records based on the Boolean within layer statements. Overlaying is specified by the Boolean between layer operations and may involve simultaneous intersections, unions, or differences. These operations, in multiple layers, can be handled in one pass by TIMBER-PAK's overlay processor.

TIMBER-PAK's query language is the only query language that we know of in which the Boolean operators relate to various map manipulations and not merely to the selection of data item values.

Specific examples of the query language use and statement types are provided in the remainder of this paper.

SYSTEM USE FEATURES

Digitizing

Only Lines are Digitized

To enter layer data into the system one must process both map and descriptive data. In TIMBER-PAK, map data are entered first and then descriptive data are matched to the map. This approach was selected over the reverse entry order because the map data itself may undergo some change during input, possibly creating a slightly different set of RU's in any one control RU than one might anticipate.

Map data are entered into the system by digitizing. We are currently using a Calma digitizer connected to a Tektronix 4051 intelligent graphics terminal.

The digitizing method itself is unusually simple. The operator needs only to trace lines according to his order of preference, making sure that the line endpoints overlap slightly with other lines if a junction is desired. Each line is assigned a unique number by which it is identified. Lines need not be followed in any specific order as long as the entire map is covered. All lines are stored in a "line pool" which the operator may add to or delete from as desired. At the end of a digitizing session, the contents of the line pool may be plotted. An example is shown in figure 1 (note the overlap of the lines). Each line has been labelled so that the operator may delete lines by number. Also, each line has now been "thinned" for maximum storage efficiency and its coordinates are referenced to the desired coordinate system (UTM in this case; other coordinate systems can be accommodated also).

When the line image of the map seems all right and no further editing is required, TIMBER-PAK automatically extracts the polygons from the line image (if the layer is a polygon layer), and a new map can be plotted in which the extraneous line endpoints have disappeared and each boundary is drawn twice. An example is shown in figure 2.

Descriptive Data are Matched to the Extracted Polygons

Since the polygons are computed by the system, they are automatically correct (except for the absence of polygons due to missing lines or non-overlapping lines). Hence, polygon editing is not required. Thus, there is no need to check for containment of holes within main polygons, to check whether boundaries are clockwise or counter clockwise, or to check whether polygons do overlap or are properly closed as is required in some other systems.

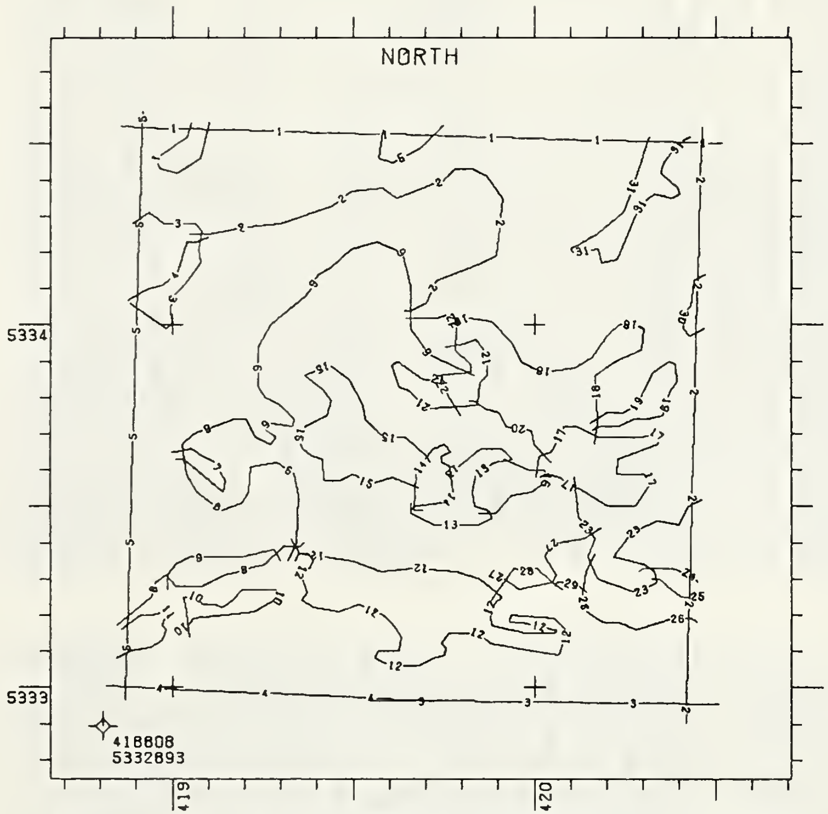
Each extracted polygon is assigned an RU number by the system (fig. 2). Now the operator may add descriptive data to each RU by assigning his data to this number.

Descriptive data are entered in free form format in the order defined by the packing table. Some editing data are currently provided by the packing table. In the near future, the system will also have the capability to check for valid data by invoking editing routines. If a descriptive record is erroneous, only the corrected record needs to be resubmitted. Descriptive data can be gradually absorbed until the layer is complete. It may then be inserted into the data base.

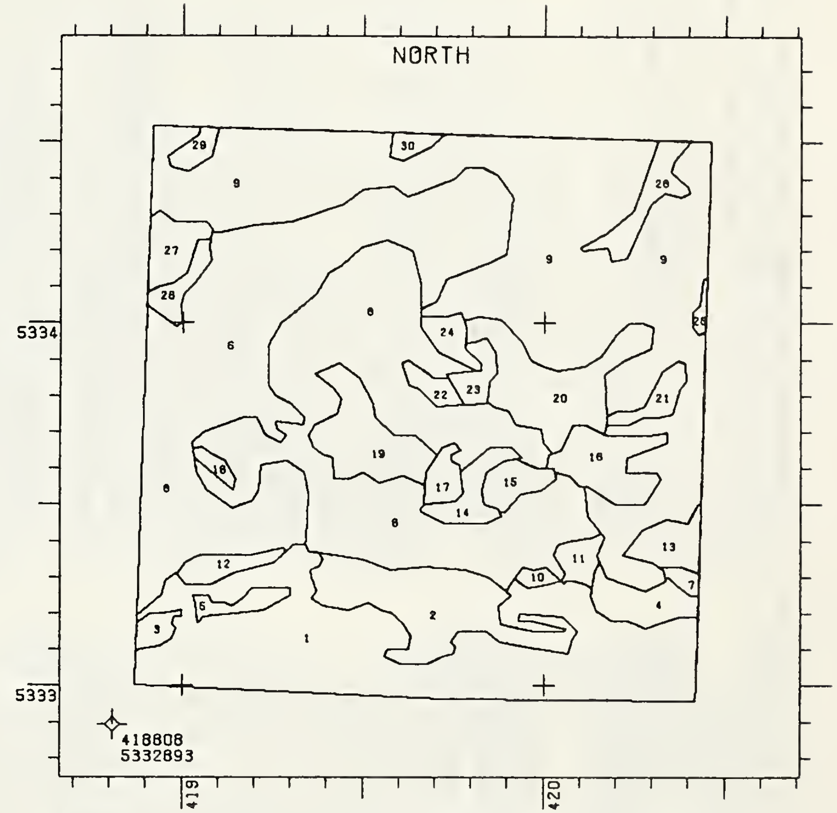
Label Locations are Variable

When the descriptive data entry is complete, a first opportunity exists to display data items (other than the RU number) within the polygon boundaries. From then on, data item value labels may always be requested by merely providing the system with the data item names. This is referred to as labelling.

Each label may consist of up to ten label lines. Each line shows the values of one data item in the order in which the data items were requested, as shown in the label legend (fig. 8). Multiple values per line may appear if the requested data item was an array. These values are then separated by commas (see, for instance, the third label line in fig. 12). Data items can be "area sensitive," and if so, their values will be multiplied with the acreage of the RU.



T31S R11W S26 WM	SECTION REPORT
SECTION ID. 9139	TRANS. 8/ 1/1977 NO.1
COVERTYPE LAYER	EXTRACTED LINES
STATUS: 8/ 1/1977 NO.1	EDIT CYCLE 1
UTM ZONE 10	WOLF TREE
SCALE 1: 11513	TIMBER CO. EARTHSAT TIMBER-PAK



T31S R11W S26 WM	SECTION REPORT
SECTION ID. 9139	TRANS. 8/ 1/1977 NO.1
COVERTYPE LAYER	EXTRACTED POLYGONS
STATUS: 8/ 1/1977 NO.1	EDIT CYCLE 1
UTM ZONE 10	WOLF TREE
SCALE 1: 11513	TIMBER CO. EARTHSAT TIMBER-PAK

Figure 1.--Digitizing. Digitized lines of covertype layer. Note how line ends slightly overlap with other lines to provide a "connection".

Figure 2.--Digitizing. Extracted polygons, computed from lines in figure 1. Overlapping line ends have disappeared. Boundaries are now plotted and stored twice.

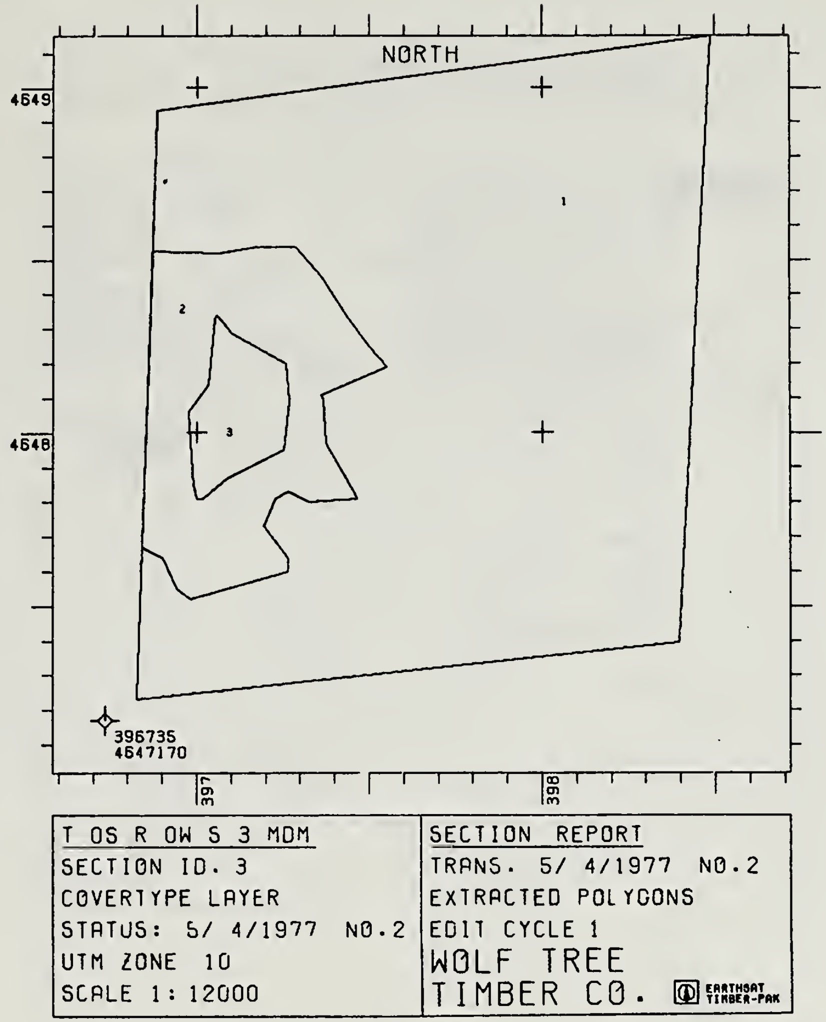


Figure 3.--Updating. Covertype Layer change map.
RU 2 is the change area; note island.

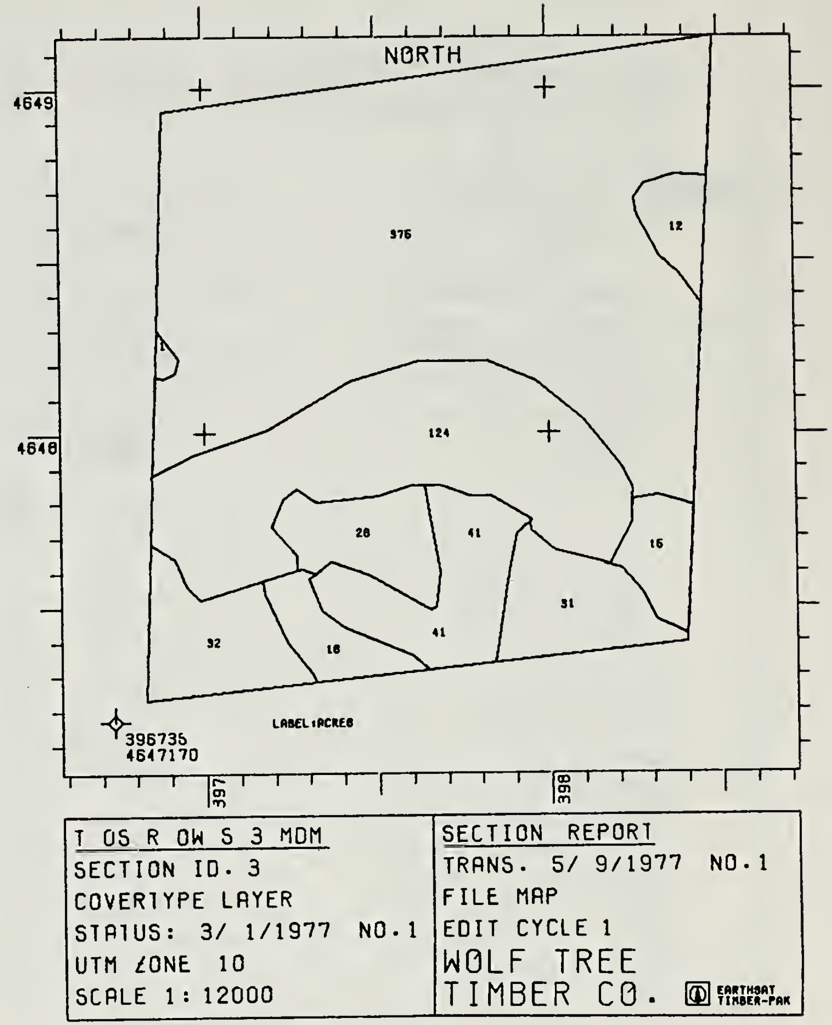


Figure 4.--Updating. Covertype file map.

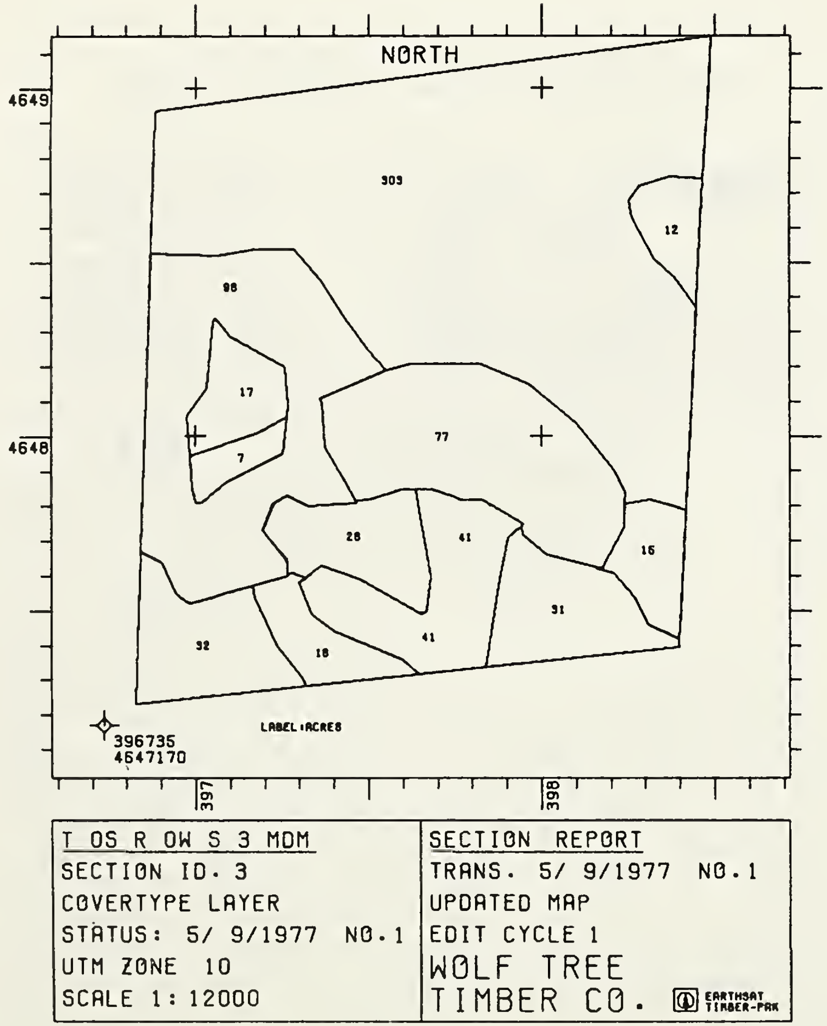


Figure 5.--Updating. Change map has been merged with file map to produce updated map.

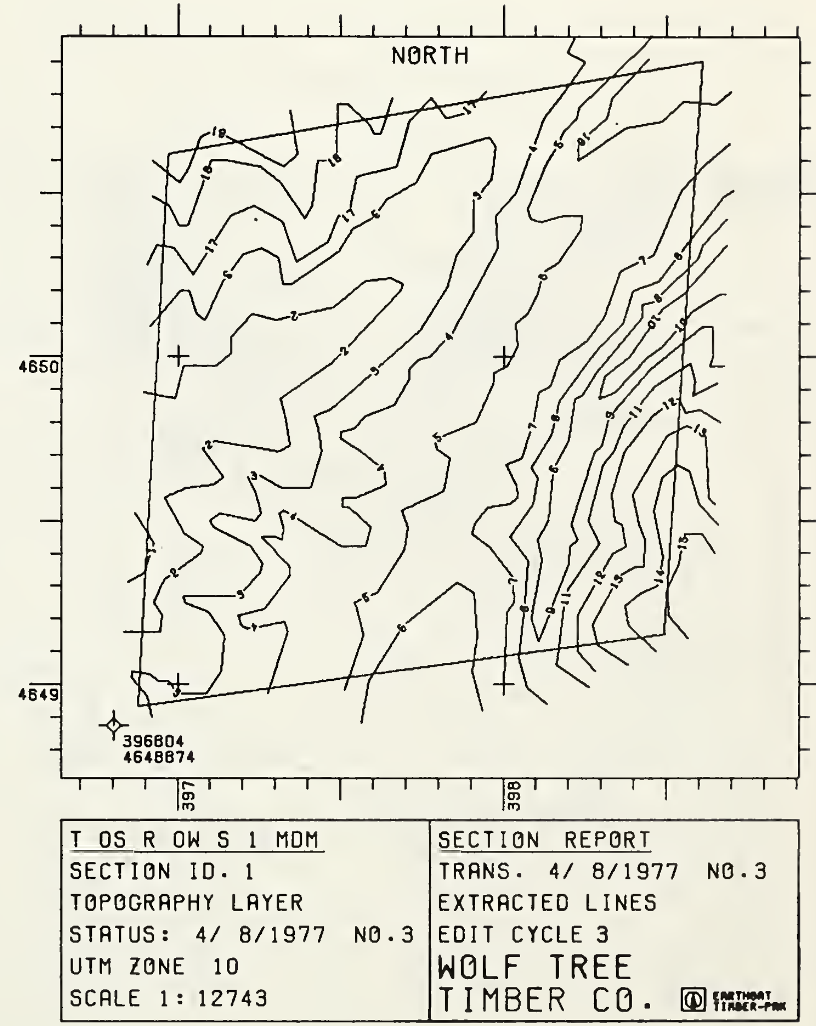


Figure 6.--Slope class generation. Contour map. Contour lines are numbered for easy editing.

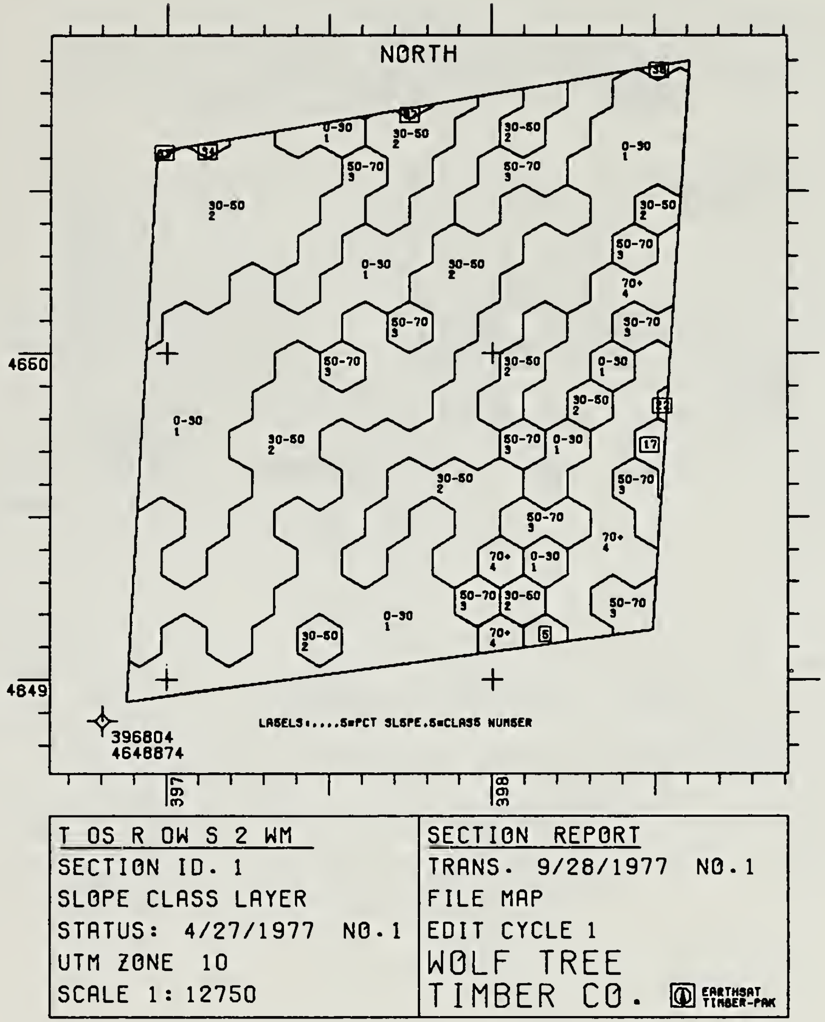


Figure 7.--Slope class generation. Slope class map. This map was automatically derived from the contour lines shown in figure 6.

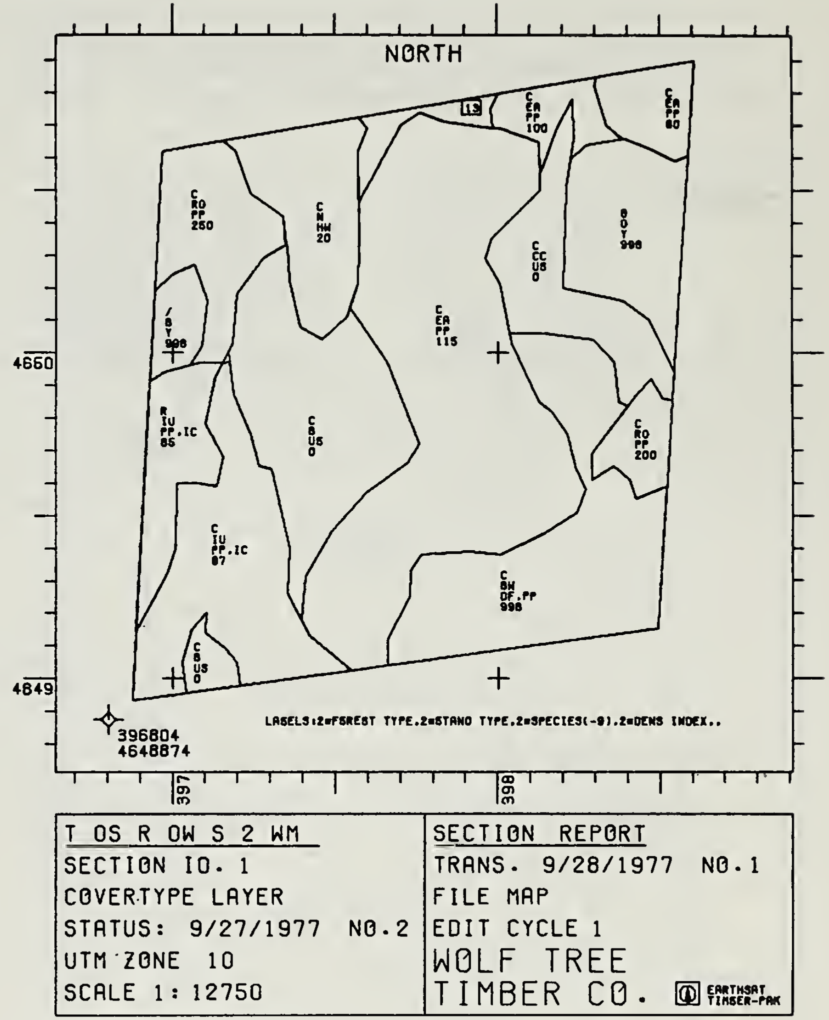


Figure 8.--Commercial thinning query. Retrieved file map of covertype layer.

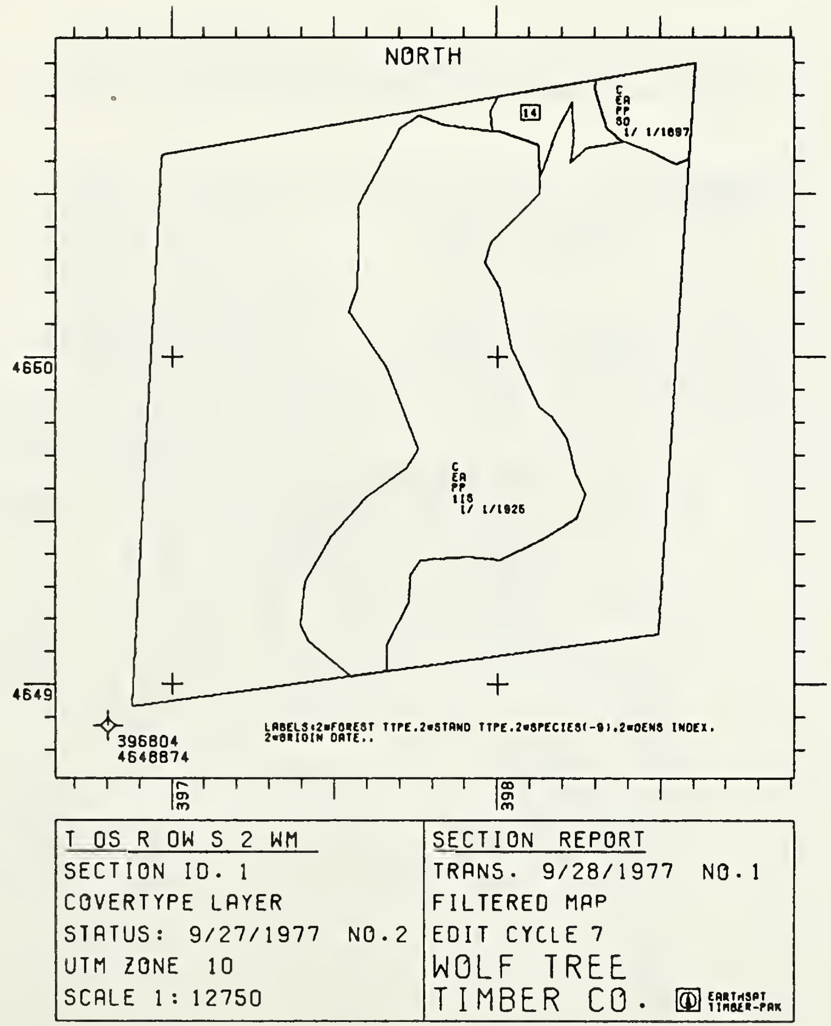


Figure 9.--Commercial thinning query. Filtered map. This map has been derived from the one in figure 8, by Boolean selection as specified in the query statements.

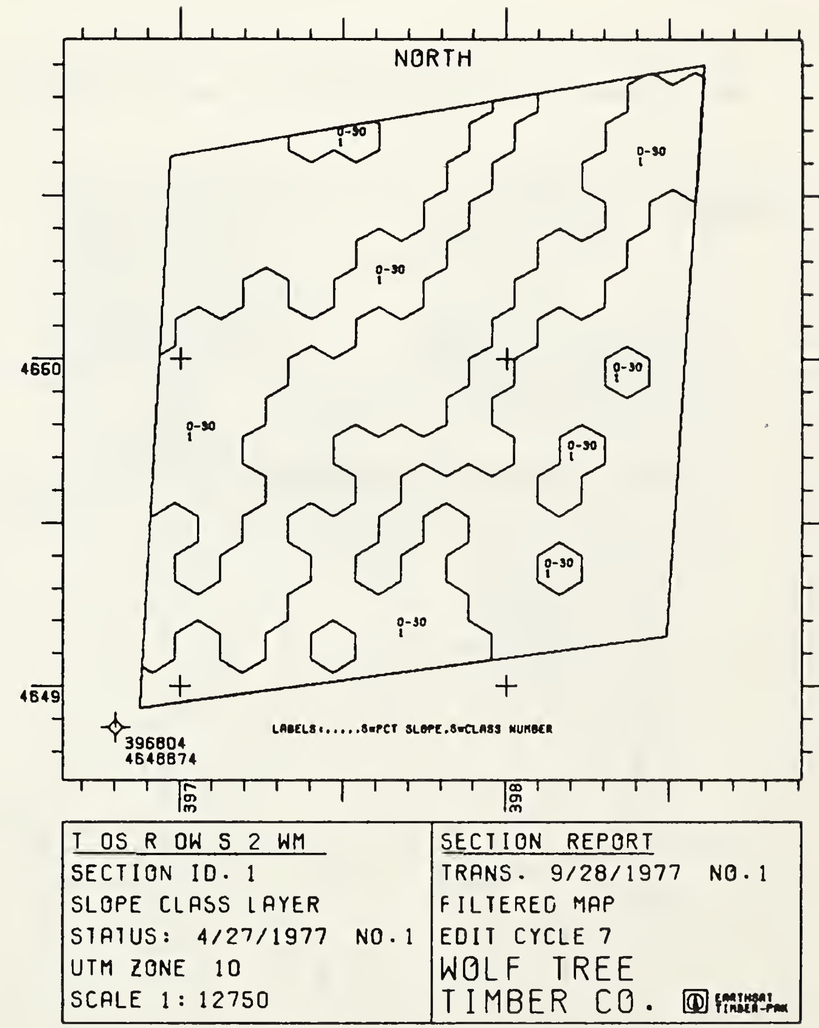


Figure 10.--Commercial thinning query. Filtered map. This map has been derived from the one in figure 7. Slope classes 2, 3, and 4 have been filtered out and only class 1 remains.

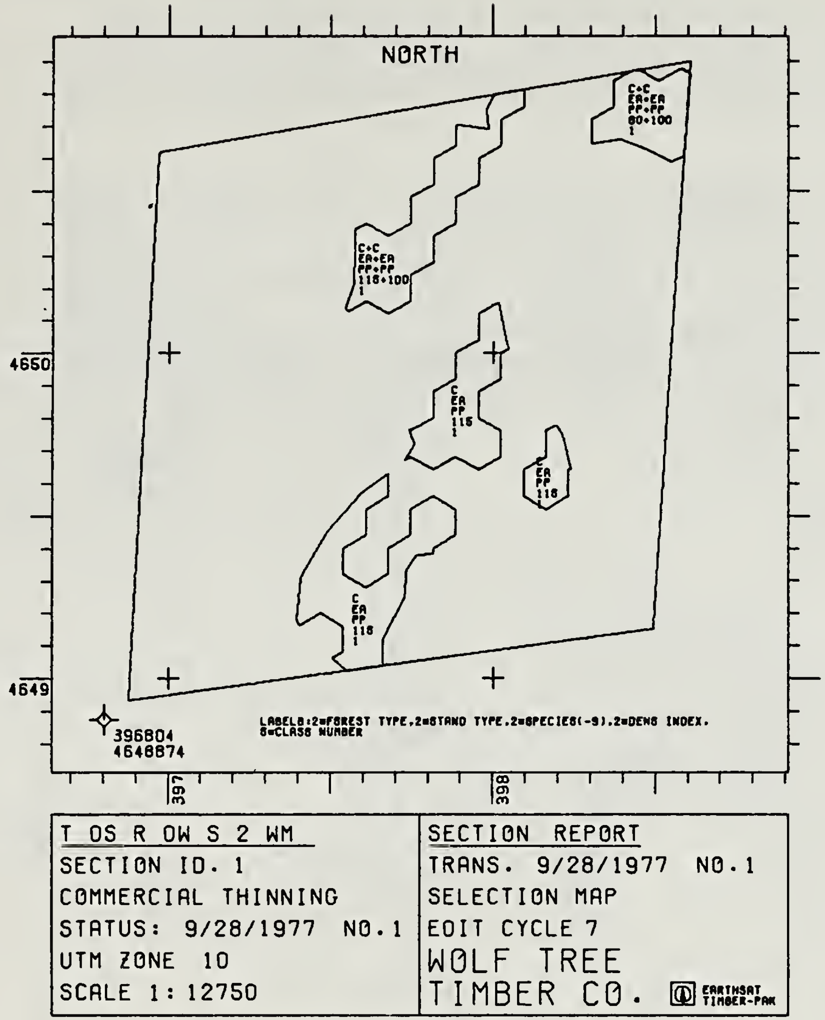


Figure 11.--Commercial thinning query. This map showing the selected area suitable for commercial thinning was derived from the maps in figures 9 and 10. This was done by means of an overlay intersection as specified in the query statements.

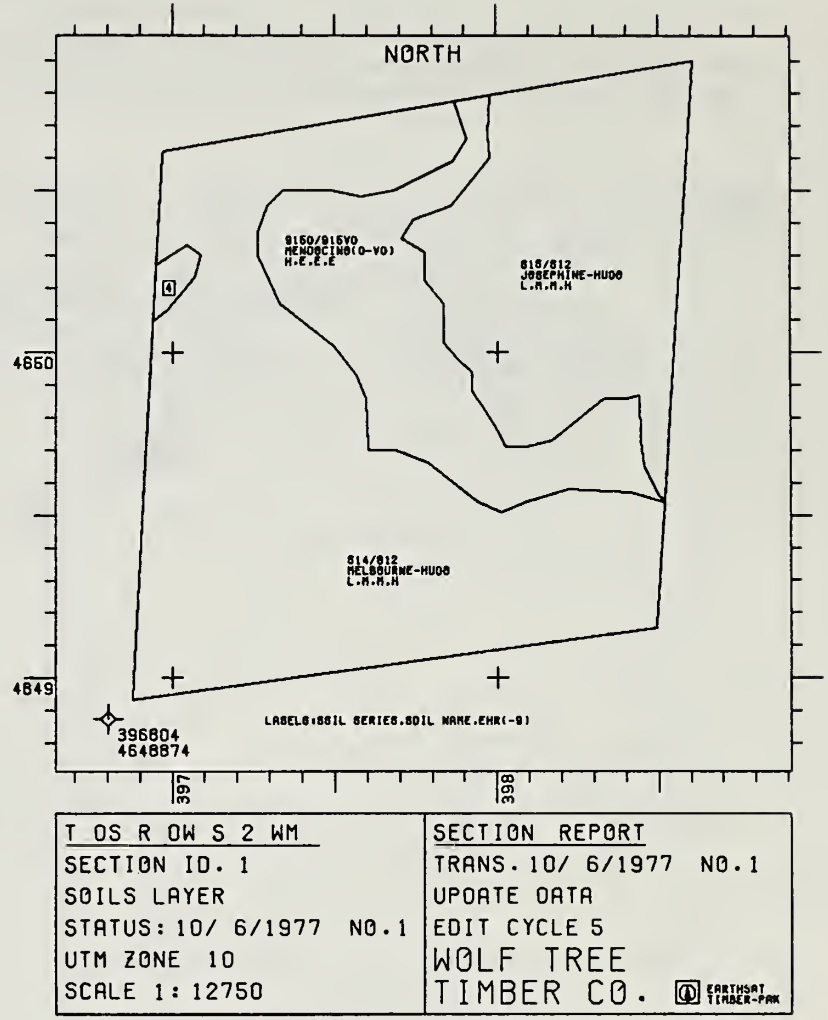


Figure 12.--High soil erosion hazard query. Soils map showing soil series and erosion hazard ratings in each of four slope classes (L = low, M = moderate, H = high, E = extreme).

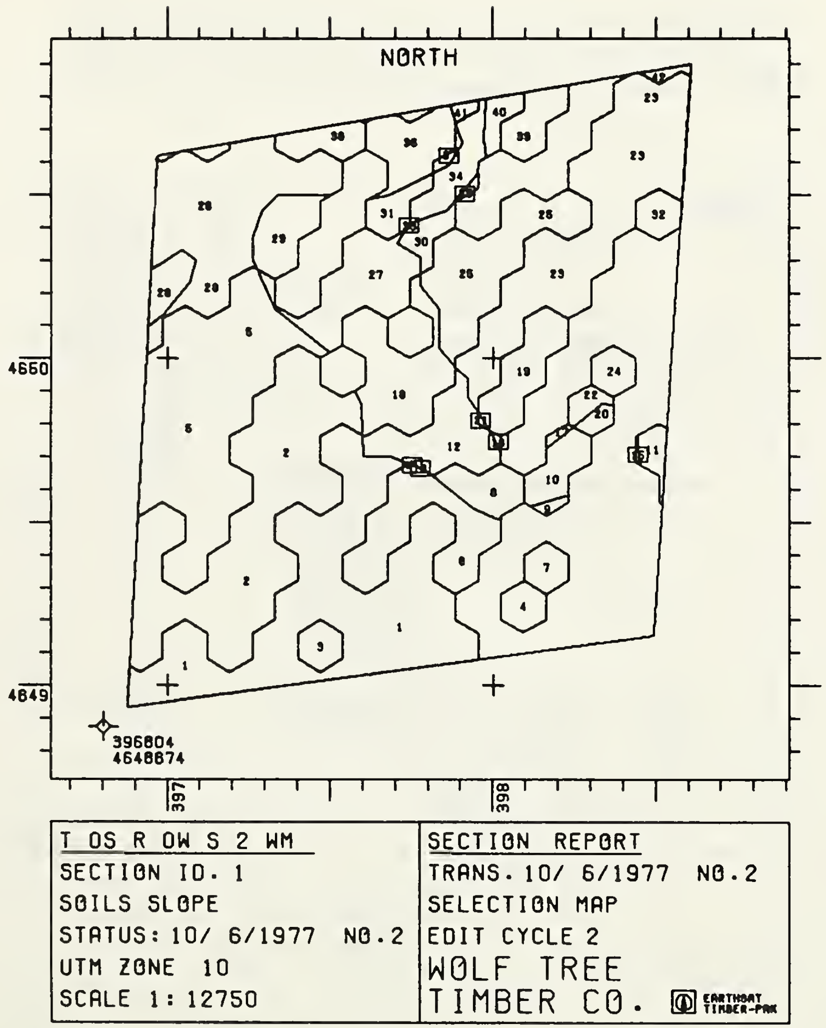


Figure 13.--High soil erosion hazard query. Selection map derived by intersecting maps in figures 7 and 12 (slope classes 3 and 4 were excluded). Each unit in this map has now a unique soil and slope class assigned to it.

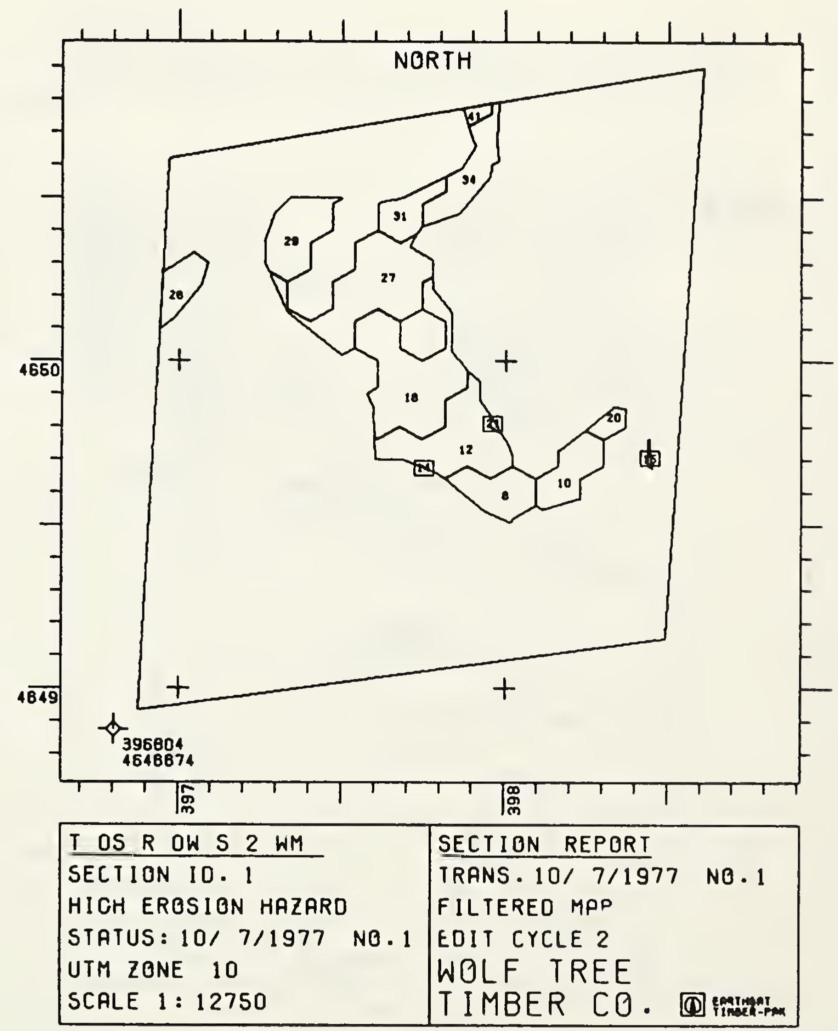


Figure 14.--High soil erosion hazard query. This map was derived by filtering the one in figure 13 for those units in which the combined effect of soil and slope yields a "high" rating.

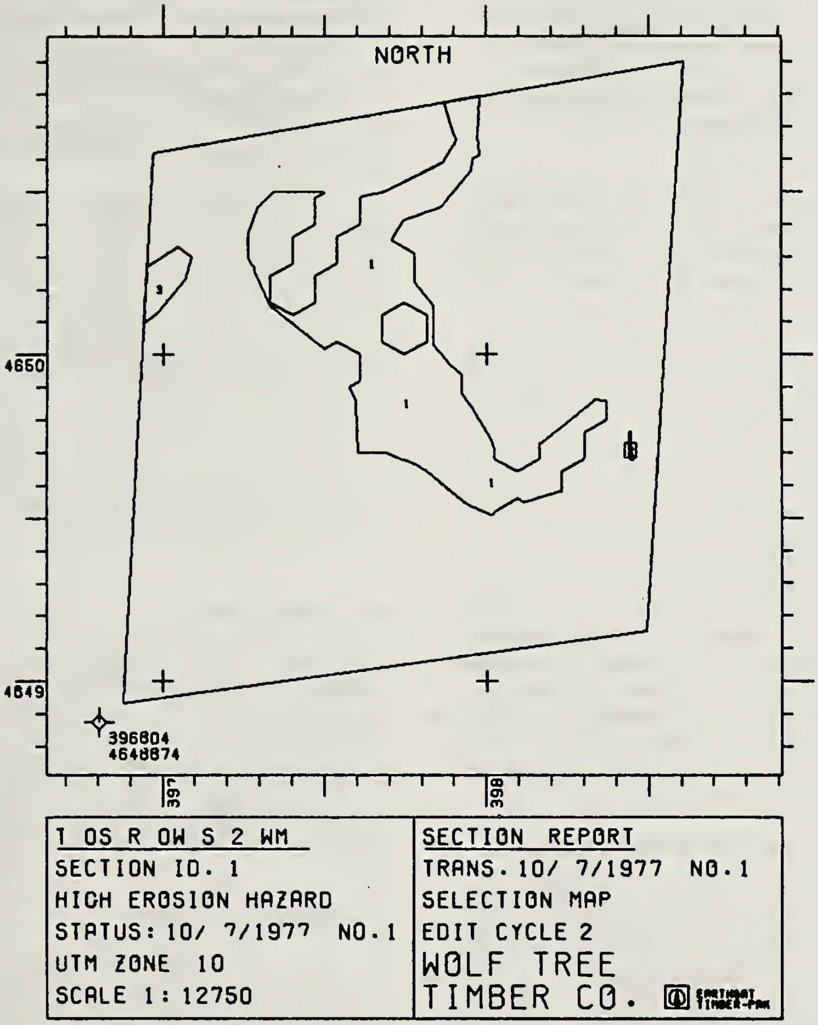


Figure 15.--High soil erosion hazard query. Final selection map derived from the one in figure 14 by taking the union of all units qualifying under the query.

Labels are automatically centered in logical locations and multiple labels may appear in any one RU; the "snakier" the RU, the more labels will appear (fig. 2). If no suitable location can be found for the label within the polygon, the RU number is plotted instead, centered within a small rectangle, meaning that one must refer to an accompaning printout for the label (fig. 9).

Labelling has been a much neglected cartographic problem (Marble, 1977). Most current systems use centroid computation to place labels. The centroid, of course, may fall outside the polygon.

With a variable label locating capability, the map itself may become a handy "mini-report" in which the report elements are shown within the polygon boundaries.

Updating

Updating is Accomplished by Merging Change Maps with File Maps

Updating has long been a much neglected aspect of spatial information systems (Tomlinson, 1972). In TIMBER-PAK, we gave much thought to the updating problem from the beginning, realizing that updating will be a frequent activity resulting from the frequent changes in the forest resource.

An update of an area is made as follows: a map is prepared on which the change area is indicated; this map is mounted on the digitizer, and only the changed area is digitized in the identical manner in which one would enter a new map. Polygons are then extracted and descriptive data for the changed area are added. This provides TIMBER-PAK with the "change map" (fig. 3). The system then automatically retrieves the file map (fig. 4) and merges the change map with the file map (if we call the change map B and the file map A, the overlay processor performs the function B OR (A NOT B)). The system assigns new RU numbers and automatically distributes the correct descriptive records to each RU. Certain "old" RU's may disappear or split, requiring the system to delete or reassign corresponding descriptive data. The resulting output map for the example is shown in figure 5.

Slope and Aspect Maps

A Hexagonal Grid is Used for Slope and Aspect Class Polygons

Slope and aspect are important factors in forest management. TIMBER-PAK, therefore, has the ability to automatically generate slope and aspect polygons from digitized topography.

A hexagonal grid is superimposed on the topography layer, and for each hexagon vertex point the elevation is estimated from the n nearest points by interpolating with a second degree surface. A least squares plane is then fitted to the six hexagon points and its slope or aspect is computed, depending on the type of layer being produced. Slope or aspect are then mapped into classes and the overlay processor is assigned the task of combining the hexagons of like class into slope or aspect polygons (these are also called polyhexes). A topography layer and corresponding slope class layer are shown in figures 6 and 7.

Two Query Examples

The real utility of the system lies, of course, in its capability to meaningfully query the data base. In the following, we will provide two examples which we hope are illustrative of the types of queries that can be made. The first locates stands suitable for commercial thinning, and the second finds areas with a high soil erosion hazard.

Commercial Thinning

The objective was to find stands of a certain age with a greater than normal density on slope classes 0-30% which could be commercially thinned. The query was formulated as follows:

1. SELECT LAYER = COMMERCIAL THINNING $
2. IN AREA = 1 $
3. WITH OPTIONS = MINIMAL SEARCH, DELETE INTERIORS $
4. FOR WHICH $
5. IN LAYER = COVERTYPE LAYER $
6. FOREST TYPE EQ 'C' AND STAND TYPE EQ 'EA' AND (SPECIES(-9) EQ 'PP' OR
7. SPECIES(-9) EQ 'DF') AND (ORIGIN DATE GE 1/1/1895 AND ORIGIN DATE LE 1/1/1940)
8. AND DENS INDEX GE 80 $
9. AND $
10. IN LAYER = SLOPE CLASS LAYER $
11. CLASS NUMBER EQ 1 $
12. END $

NOTE: The $ sign indicates the end of a statement, each statement line is numbered.

The name of the secondary layer, COMMERCIAL THINNING, which will result from the query, is defined in the first line. This name will appear in the plot annotation block, and when the secondary layer is again input into some other query, it must be referenced by this name.

In the second line the geographic area in which the query is to be performed is specified. Here 1 is the internal I.D. of the section (control RU). Normally, instead of one section, a list of sections or control RU's would be provided.

MINIMAL SEARCH in the third line means that units in which there are unknown data item values will not be considered (throughout the system, unknown values are handled in a consistent manner).

DELETE INTERIORS in the same line means that interior boundaries in the final output will be erased (a final union is performed) so that only disjoint units will remain.

The FOR WHICH statement of the fourth line indicates the beginning of the Boolean clause. Within this clause the "within layer" conditions are preceeded with an IN LAYER statement (lines 5 and 10). The "between layer" specification is an AND statement (line 9). It will trigger an overlay intersection.

Lines 6, 7, and 8 contain the selection statement for the covertype layer. FOREST TYPE, STAND TYPE, SPECIES, DENS INDEX, and ORIGIN DATE are all data item names. The symbols enclosed in quote marks have the following meaning: C = Commercial, EA = Even Aged, PP = Ponderosa Pine, DF = Douglas Fir. SPECIES (-9) means that all species codes in the species composition matrix are to be inspected for a match with 'PP' or 'DF'.

CLASS NUMBER in line 10 refers to the slope class number; 1 means 0-30% slope.

Once the query has been compiled, the file maps for the designated sections (fig. 7 and fig. 8) are filtered according to the statements for each layer. The resulting filtered maps for the queries are shown in figures 9 and 10. The filtered results are then overlayed according to the "between layer" statements and the interior boundaries are deleted. The final selection map is shown in figure 11.

The units in the selection map are called secondary resource units (SRU's). Each may have several "parent RU's". For instance, the label line C + C means that the SRU has two parent covertype units, both with a commercial forest type rating.

High Soil Erosion Hazard

This query demonstrates another essential capability of TIMBER-PAK, namely to use the outputs of queries as input for subsequent queries. That this capability is needed to find areas with a certain soil erosion hazard qualification arises from the fact that the erosion hazard is both dependent on soil type and slope. Figure 12 shows the soils map for section 1 in which the third label line lists the erosion hazard matrix such as L, M, M, H. Element 1, (L) assigns a low rating to a slope class 0-30, 2 (M) a moderate rating to class 30-50, 3 (M) a moderate rating to class 50-70, and 4 (H) a high rating to class 70+. Thus, in order to know the rating for a given soil type, one must know the slope class. So an intersection between the soils map and the slope class map must be made to assign a unique soil and slope to each SRU in the intersection map. The intersection map is shown in figure 13. It is the result of a query in which all soils units were intersected with slope classes 1 and 2, under the assumption that we are only interested in working on terrain with these moderate slope classes. As a result, there are some unlabeled areas in figure 13 where slope classes 3 and 4 have been filtered out.

With the soils slope intersection map in hand, we now pose the following query:

```
1. SELECT LAYER = HIGH EROSION HAZARD
2. IN AREA = 1
3. WITH OPTIONS = MINIMAL SEARCH, DELETE
   INTERIORS
4. FOR WHICH
5. IN LAYER = SOILS SLOPE OF 10/6/77,2
6. 7*EHR(5*CLASS NUMBER) EQ 'H' OR
   7*EHR(5*CLASS NUMBER) EQ 'E'
7. END
```

In line 5, we now request a secondary layer, the soils slope layer, as input. It is identified by its name as well as the transaction date and number so that the system may locate the data in the workfile.

Line 6 demonstrates how in this secondary layer we are now able to refer to the appropriate erosion hazard rating by indexing the corresponding data item name with the slope class number. Each data item is preceeded by the primary layer number (5 = slope class, 7 = soils) because the secondary layer is composed of two parent primary layers.

For each unit the system will now retrieve the slope class number and use this number as an index to the erosion hazard rating matrix. The resulting value is then inspected to see if it matches "H" or "E", and if so, the unit is input

to the overlay subsystem. The filter map for this query is shown in figure 14 and the final selection in which the union of all units has been computed by the overlay processor as shown in figure 15.

CONCLUSIONS

Although the name TIMBER-PAK implies that the system be used only for timberlands management, it goes without saying that it is applicable to other kinds of natural resources as well.

What ever the final management goals may be, a system such as TIMBER-PAK can be used to store and update inventory data of all kinds of resource components so that they can be readily brought to bear on vital management interests. We hope that this EarthSat system will promote some progress in this area.

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Computer-Assisted Resource Management[1]

Larry E. Beeman[2]

Abstract.--Successful planning processes for allocating natural resources recognize (1) the interrelationships of natural resources and processes, (2) the appropriate socio-economic forces, and, (3) the link between information and the quality of resource decision-making. A computer program, IMGRID, is briefly described that can assist decision-makers in data handling problems associated with resource planning/ management.

INTRODUCTION

The interrelationship among resources -- natural ecological processes -- is a resource in itself. In order to consider "all" resources and man's use of these resources, we frequently collect literally volumes of data and somehow, almost mysteriously, sketch a master plan. It's called comprehensive resource planning. Even though faith in the grand design is stronger than ever, it is false to think that once a noble design is placed on paper that its reality will follow.

It is important to comprehend that most often people who are planning the way for resource allocations and the people who control these resources are quite different parties. For most regional resource plans to succeed, a spirit of cooperation is needed among governmental agencies and the citizenry of the region. The political atmosphere of regional planning cannot tolerate diffuse independent actions by planning agencies. A commitment is needed to a "planning process" that recognizes first the importance of input from various points of view, and, secondly, a technique methodology that adequately evaluates pertinent resource and socio-economic information. The socio-economic interests are very powerful forces and not incorporating their influence is an invitation to a regional planning disaster.

Planning agencies in the past have been staffed primarily by people concerned with physical design and development. Ecologists have been operating on the fringes and usually have not been influential in resource planning. Foresters have concerned themselves with the forests; wildlifers have concerned themselves with wildlife; highway planners have concerned themselves with road engineering; city planners have concerned themselves with green belts and human related development; and the list goes on. All these specialized interests provide important contributions to society, but, since the action of one affects the action of another (many times in a counterproductive manner), why does each specialized interest work independently? It seems a poor way of conducting business.

All too often the vital link between resource decision-making and information is not recognized. Frequently, considerable time is devoted to collecting information and far too little time committed to creative thought for preparing information in a format suitable for interpretation by decision-makers. Most master plans to date make the colossal jump from "pertinent" resource information in raw format to a final plan. The route traveled -- information used, analysis conducted, alternatives considered, etc. -- is left to the fancy of the reviewer. In most situations, one or two "overriding factors" -- usually economic -- totally influence the final plan and the remaining resource information serves only to fatten the appendix in the master plan.

Ideally, predictive models that display precisely -- or as near to precise as our present knowledge allows -- the consequences of an action or cumulative actions should be available to resource decision-makers. Such models display the interrelationships of ecological processes and the relevant economic, social, and political forces. The goal of this process-oriented approach is to give resource planners/managers visibility of various perturbations before implementing plans and to determine the consequences to natural resources. In other words, the

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objective is to allocate resources to make the best fit between land capability and resource use.

A computer technique, IMGRID, is briefly described that can assist in some of the data handling problems previously mentioned. The computer, while offering flexibility in data analysis, interpretation and presentation, does not give us the gift of prophecy. Without a proper planning process, use of IMGRID, or any data handling technique for that matter, cannot survive the implementation rigors of the real world and will die between the covers of a planning report.

METHODS AND TECHNIQUES

Data Handling

Conventional techniques are frequently adequate to assist resource planners in site specific management decisions. Maps with hand-drawn information (DeVos and Mosby, 1969) may be sufficient for small areas where geographical variation of resources is limited and the interrelationships of those resources are relatively simple. For areas that are more complex or require more detailed analysis, transparent hand-drawn overlay maps may provide adequate information for decision-making (Crozier, Fuhriman, and Robinette, 1974). However, overlay maps have the following limitations:

1. Analysis is limited to the coincidence and proximity of resources (subtle value distinctions and quantification of data are difficult).

2. Visual interpretation of overlay maps becomes increasingly more difficult with each additional map.

3. Updating and maintaining current resource information and land-use changes on overlay maps are expensive.

4. Overlay maps become unwieldly, costly, and inefficient as land area increases in size, complexity, and land-use potential.

The selection of a data handling technique is critical, although, more than one technique can serve equally as well. Data handling techniques should be used as a tool to clearly and concisely interpret data for decision-makers. If used to the maximum benefit, subjectivity is minimized and limited to the data manipulative steps of the decision-making process. In other words, model results are data manipulations based on ecological and socio-economic principles. The results are visual, site specific and require little to no further interpretations by the planner/manager.

If use of hand-drawn techniques is fully adequate to supply sufficient interpretations for the planner, there is no need to involve the computer. As information and/or the interrelationships among resources increases, a point is reached when computer techniques are the most effective and efficient method of handling data.

Computer Program

The computer-assisted data handling technique, IMGRID, is a package of computer programs developed by Sinton (1976). Two important attributes make IMGRID especially applicable to resource management planning. First, IMGRID allows highly efficient manipulation of geographical data for production of maps with site specific resource interpretations. Second, IMGRID was designed for use by non-programmers, therefore, its operation is dependent on an understanding of resource management and not training in computer programming.

The IMGRID program uses grid cells to transform information from resource maps into a digital format. A grid is superimposed on each of the resource maps and forms the basic unit for coding. The irregular polygon shape of most resources can be approximated by decreasing the size of the grid cells. Figure 1 illustrates data transformation and gives examples of the following three terms.

1. Data element - A mutually exclusive set of information that describes a natural resource or land-use unit (e.g., soil-mapping units, forest cover, water resources, roads).

2. Data item - Data items represent the descriptive information in each grid cell which collectively make up a data element (e.g., oak-hickory forest type is one data item in the forest cover data element).

3. Data file - A collection of data elements that are stored as a unit for retrieval and processing.

The output of IMGRID includes two related pieces of information. A map is printed that displays site specific resource information. This may be as simple as one data element (e.g., forest cover) or as complex as a model identifying the suitable areas for a nuclear power plant. In addition, a histogram that quantifies, as well as identifies, information accompanies each map (fig. 2).

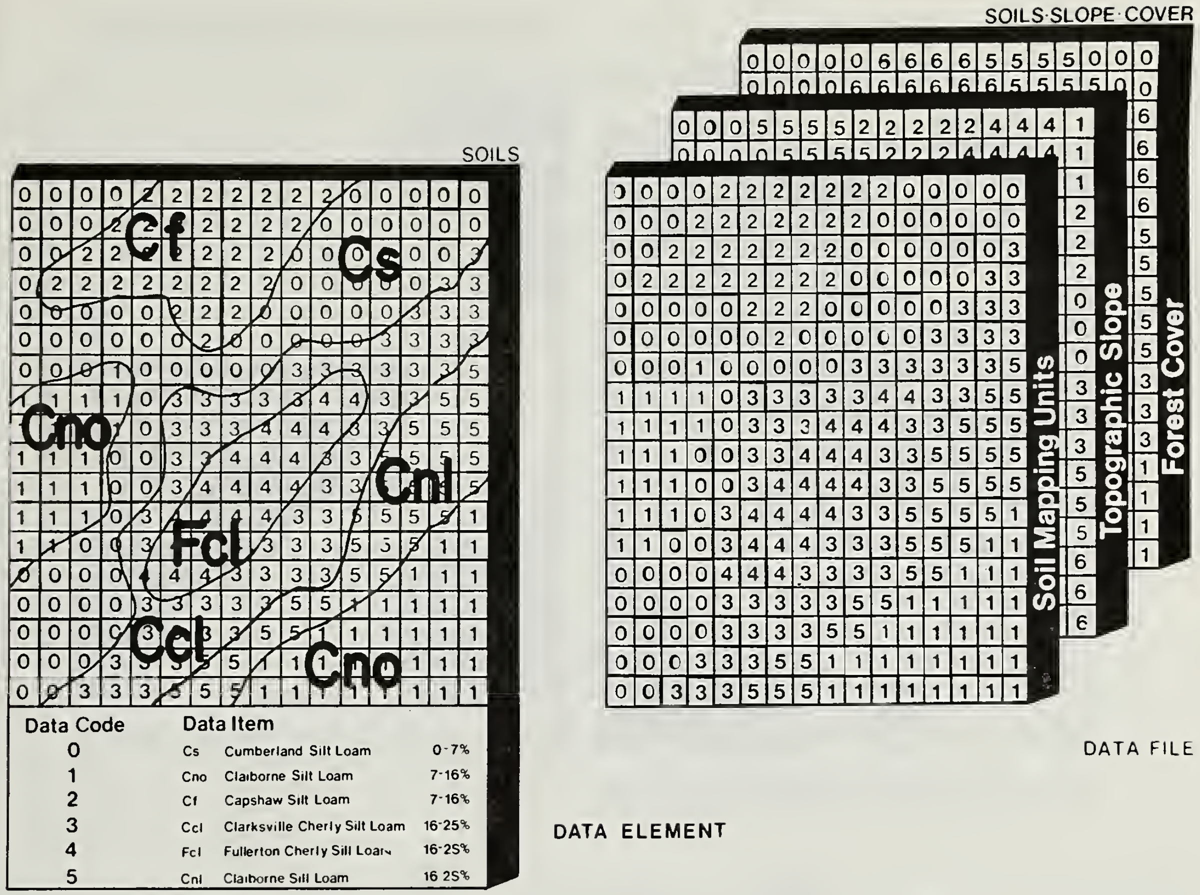


Figure 1.--Converting resource information into a computer-compatible format. Data items (descriptive information) are assigned data codes (numerical designation) for each data element (a mutually exclusive set of data such as soil mapping units). The collection of data elements creates the data file.

Data Management

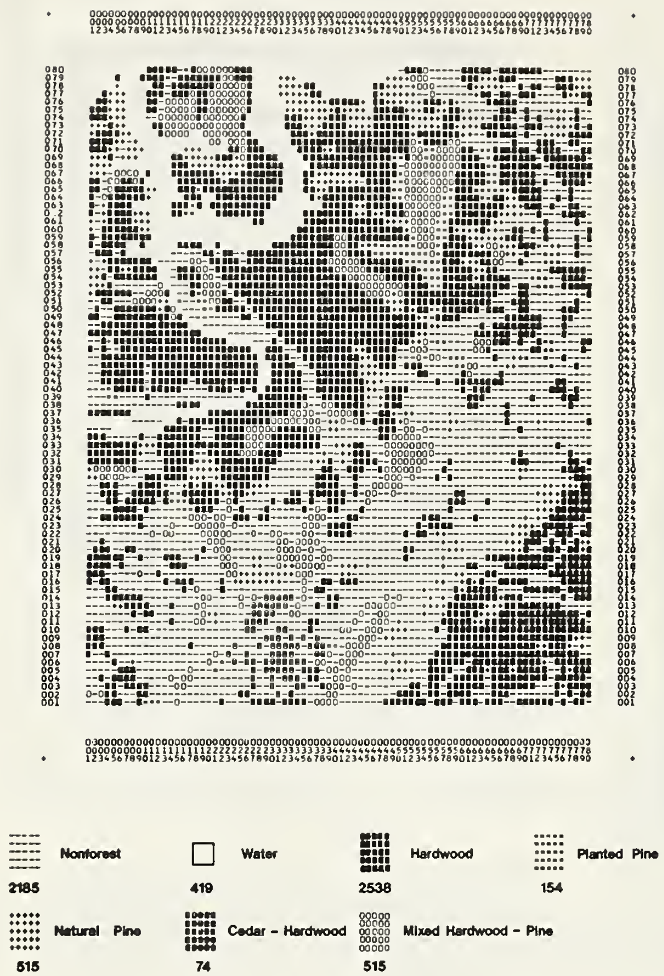
Long-term comprehensive resource management requires a reliable information bank. To accommodate land-use policy changes or simply to have access to the geographic location of existing resources for management prescriptions, planners need permanent and retrievable records of resource inventories and analyses at their immediate disposal. This is especially valuable where land-use patterns are changing rapidly, or when outside interests are placing constant demands on the system for information.

Resource information is updated easily and economically using IMGRID. Rather than changing the entire data element, only the geographical area affected by the change is updated. For example, if 100 acres (40.5 hectares) of timber are clearcut in a mature forest stand, only those grid cells describing timber size in the clearcut area are updated in the timber size data element. This permits planners to make site specific land management decisions with current and reliable information.

DATA MANIPULATIONS

Data Interpretation

IMGRID is extremely flexible in manipulating data for ecological and socio-economic interpretations. Different interpretations from one data element is possible. For example, each soil mapping unit has an interpretation for erosion hazard, productivity, septic tank suitability, etc. Without the assistance of the computer, it is necessary to manually reclassify and redraft the original soil survey map for each interpretation. With IMGRID, the original soils document is handled only once for coding the soil



FOREST COVER

Figure 2.—A computer-generated map displaying forest cover types in 2.68 acre (1.1 hectare) grid cells for a 17,090 acre (6,919 hectare) area. The extent of each forest type can be calculated from the product of cell size and number of cells in each forest type.

units in grid cells. Interpretations are defined by the soil scientist while the mechanical steps of sorting, classifying, and mapping are executed by the computer.

Coincidence of Resources

IMGRID programs are designed to superimpose data and print various coincidence of resources. For example, data identifying timber stand type, timber stand size, and position on slope could be superimposed to identify areas of potential mast production, a critical habitat parameter for many wildlife species. The IMGRID programs allow superimposing any number of resources, although the complexity of interpreting mapped results increases with each additional combination.

Proximity of Resources

The capability to identify proximal distributions of resources is another important attribute of IMGRID. Figure 3 graphically displays areas that are not in close proximity to surface water. To identify these areas, a search was performed by the computer from permanent water sources. This map could be used to identify areas where constructed waterholes would enhance the habitat for certain wildlife species. The IMGRID user has complete control over distance of searches and can dictate

PROXIMITY SEARCH

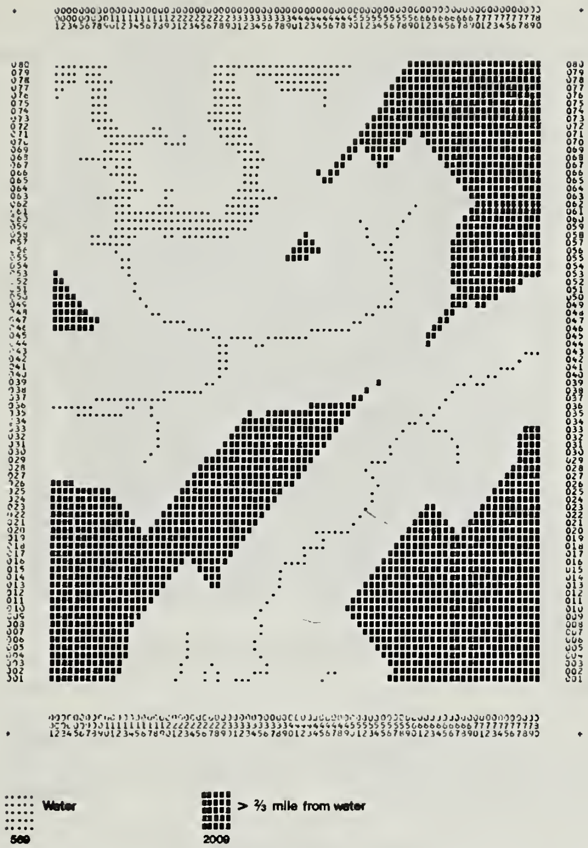


Figure 3.--A computer-generated map that identifies areas greater than 2/3 mile (1.1 kilometers) from permanent surface water sources.

practically any radius appropriate to the analysis.

Resource Management Models

The interrelationships of ecological processes and land-use variables frequently accumulate to a level of incomprehension when viewed as a whole. Models are useful in providing a formal system for breaking ecological processes into "manageable units" for resource planners. The computer is useful in mechanically reconstructing the interrelationships of these "manageable units" back into the whole and printing the results.

IMGRID can weight resources according to their relative importance and map the results. Two types of weighting are possible: (1) internal - the mathematical weighting of data items within one resource (e.g., oak-hickory forest type in the forest resource); (2) external - the mathematical weighting of resources against each other (e.g., the relative importance of soils, forest cover, etc. in a model). After assigning weights, IMGRID sums the product of internal and external weighting, assigns each grid cell a numerical value and prints the results as symbols on computer-generated maps. In effect, potential interrelationships of resources are being established by assigning mathematic values to ecological principles.

Table 1 shows the weighting for a white-tailed deer habitat model. For purposes of illustration, potential mast producing areas, potential browse availability and proximity to water were identified as important habitat parameters for deer. "Submodels" were constructed for each habitat parameter by using pertinent ecological information. Next, areas were identified that possessed a suitable interspersion of the three habitat parameters. In other words, the model first evaluates the area for the individual habitat parameters and then identifies the proximity of these parameters (fig. 4).

Frequently it is useful to know what influences the final results of a model. For example, why is a section of the project area

Table 1.--An example of how resources are mathematically weighted according to their relative importance. Potential white-tailed deer habitat is identified by relative weights assigned to data elements (external weighting) and data items within these data elements (internal weighting). The results of this deer habitat model is shown in figure 4.

Data Element	Internal Weighting					External Weighting	Habitat Parameter
Forest Cover	Hardwood	Hardwood-Pine	Cedar-Hardwood	Pine			Hard mast potential
	9	7	7	1		1	
Forest Stand Size	Seedlings and Saplings	Pole Size	Sawtimber				
	0	2	9			2	
Canopy Closure	25 Percent	25-50 Percent	50-70 Percent	70-90 Percent	90 Percent		Browse potential
	9	9	7	5	1	3	
Soil Productivity	High	Fair	Poor	Very Poor			
	9	7	5	2		2	
Position on Slope	Bottomland	Bottom 1/3 slope	Mid 1/3 slope	Top 1/3 slope			
	9	9	7	5		1	
Water	Intermittent streams	Perennial streams	Ponds	Clinch River	Norris Reservoir		Permanent water availability
	search 3/8 mile						

poor deer habitat -- what is the limiting factor? With IMGRID, "snapshots" can be taken along the way that print data manipulations at various points in the model. From these "snapshots" the resource manager is given the visibility of the various steps within the model and can isolate key ecological relationships.

A baseline model of this type also enables a look at various land management scenarios prior to implementation. Resource planners are given the opportunity to mimic ecological perturbations and determine the consequences to natural resource processes before implementing proposals.

As well as baseline models, models identifying suitable areas for management prescriptions, designated land uses, or other actions are possible. Ideally, a system of models would include regional and site specific ecological processes and the relevant socio-economic forces. Then models identifying a reallocation of resources could be related to the baseline models. This would allow a process-oriented approach to decision-making for resource planning and management.

CONCLUSION

IMGRID is a powerful resource planning/ management planning tool. Resource managers are still grappling with procedures that can inventory the interrelationships of resources and make inferences about allocation of these resources. While the resource manager uses a complex reasoning process when judging the interrelationship of natural processes, there is a fundamental methodology underlying his actions. Specifically, resource managers progress through a system of "resource pattern recognition" (Williams, Russell and Seitz, 1977) and determine the relative importance of resource relationships.

IMGRID can be used to aid and formalize the thought process of establishing interrelationships of resources. It can manipulate data under the direction of resource specialists and display the results. Besides forcing resource specialists to think clearly, concisely, and comprehensively, the maps offer quantitative interpretable information that is easily examined, compared, and communicated.

IMGRID or other computer-assisted techniques are not applicable in many planning processes. Manual techniques are frequently adequate. The

DEER HABITAT MODEL

Figure 4.--A computer map displaying potential white-tailed deer habitat as defined in table 1. The model first identified three habitat parameters (availability of hard mast, browse and water) and then located the proximity of these parameters. In this example there are 2,136 cells (2,308 hectares) where all three habitat parameters are in close proximity to each other.

appropriate data handling technique depends largely on the quantity of data, detail of analysis, output best suited for the decisions being made, financial constraints, time frame and the decision-makers.

Finally, it needs to be said again that regardless of technological advances or data manipulative techniques, a resource management project is doomed without a planning process. The planning process must obviously recognize precise objectives. But of equal importance, the planning process needs to consider the political devices for implementing plans. Regional resource planning projects will fall far short without proper recognition of policing land use (zoning) or somehow controlling land use through easements, taxation, fee simple or other innovative approaches. While the problem appears awesome and complex, it is crystal clear that progress is only possible when disciplines and agencies put aside their special interests and rally to a common cause.

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Resource Management Systems — The Cost[1]

D. R. Johnston[2]

The capability and cost effectiveness of any Resource Management System can only be judged in a real environment where useable products are being produced. In evaluating systems the user must decide whether he is going to buy an existing system or take the more costly and time consuming route of developing his own. Using a Data General Eclipse computer the operating costs of the Comarc System are discussed along with methods of increasing the effectiveness of data utilization. Specific examples of data output and related costs are illustrated.

In listening to the various papers during the past three days I think it's safe to say that resource management is not getting any less complex but to the contrary—as Yale Professor of Forestry, George Furnival, said at one of these conferences three years ago, "Things are not going to get any better; they are going to get worse. Computing will become more expensive and programmers will become even more arrogant." We employ both computers and programmers in our business--but I am going to play it safe and just talk about computers--how we use them in resource management and what our experience has been in terms of cost.

We have a resource management or what we call a geo-based information system which has been developed during the past seven years. Our approach was that of a user developing software for direct application on a variety of real-life projects in planning, environmental and engineering studies as well as resource management. Consequently we began, and continue to be both a developer and a user of systems and our clients come to us for both a service as well as complete operating systems.

One of the first questions an investigator must resolve when considering a GBIS is whether he is a system user or a system developer. The answer to this would seem obvious but for many people venturing into this technological jungle they very often get lost and quicly lose sight of their original objective. Many groups who claim to be users are, upon investigation, really developers. In certain cases some people have been charged with the task of developing a system regardless of the cost. Others who, by not asking the right questions when acquiring a system, find themselves thrust into the developer role because their new system will not perform the tasks they expected of it.

The purpose of any geo-based information system is never realized until the system is in full production. Research studies, demonstration projects and prototypes are sometimes necessary steps towards getting a GBIS into production, but they should not be mistaken for the final product. The capability and cost effectiveness of any system can only be judged once it is in full operation. This is very important to recognize because of the complexities of operating a GBIS in a production environment. Tasks which were novel and exciting during the research and development stage become mundane and boring when in production. Demonstration project data sets can be carefully selected and controlled whereas in real life they are fraught with inconsistencies and surprises which must be resolved. When doing a prototype project, budgets and time schedules tend to be liberal and forgiving. On commercial projects the budget and time constraints are very real with someone paying money for a final product, and not being satisfied with

[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan. 8-12, 1978.

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the comment—"Well, we have uncovered some very interesting problems."

Because of the very real difference between the research lab and the real application, it is imperative that any evaluation of a systems cost be based on its cost in an ongoing, commercial environment where real, useable products are being produced. The subject of this paper, therefore, is the cost of an operating GBIS.

The purchase price for an average configuration of one of our systems with a Data General Eclipse computer is approximately $5000 per month amortized over a 5 year period. This includes full maintenance and instruction.

In our shop we use a system approximately 600 hours/month which results in an hourly cost of $8.33. By the time you add overhead to this, the cost is approximately $18-20/hour for all partitions. With two terminals and partitions on the system, the cost per processing station is reduced to less than $10/hour. Therefore, if a complex polygon overlay takes 3 hours to run, the cost is less than $30. While the system is processing the overlay in one ground, the operator can be at the other terminal editing,digitizing, or running a second overlay or other operation. Meanwhile, a plotter can be running in the background, which further reduces the actual cost of each station. With the advent of the Data General Advanced operating system which will support up to 64 terminals in simultaneous operation, it is easy to add additional stations and thus reduce the cost per station of the overall system. The cost of a terminal and core for an additional station is less than $10,000. Amortized over a 5 year period and adding in maintenance and overhead this amounts to approximately $1.20/ hour for an additional station when used full time or $2.40/hour when used half time. This results in the cost/station for 3 stations being about $7/hour. To keep this in perspective, bear in mind that plumbers working for the City of San Francisco get $17/hour. Obviously, as you move into larger and larger operations, the cost per station drops. There will be points in the expansion of the system where additional discs, tape drives, line printers and other peripherals will be needed, but amortized over several terminals their cost/hour of operation will be small. An alternative to purchasing your own system is to utilize a time-sharing mode.

Our own experience in this configuration was that when we changed from the use of a main frame through a remote job entry to our own mini computer, our costs dropped by more than 75%.

In acquiring and implementing a system a potential user must consider all three elements:

i) the implementation of a system,

ii) the daily operation of a system,

iii) the efficient utilization of the systems output all are equally important. If it takes 6 months to a year, or longer, to implement the machinery the cost of amortizing the equipment over the operating life of the system becomes prohibitive. On the other hand, the system may have been acquired at a bargain rate, but if the user quickly finds that it is ineffective in a production environment--it was no bargain.

And if output can be generated at a reasonable cost but the end product cannot be effectively utilized by the user then it was all for naught. When viewing the cost of a GBIS, then, it is ne essary to constantly think of the total cost of a useable product.

Another factor in system costs is how many functions can the system perform. Consider these 2 aspects: first, can the system be useful in enough ways so that it is fully utilized and secondly, can it perform enough functions on any one data file to lower the cost of encoding. In any resource management system, getting data into the computer is one of the most expensive factors, so obviously, the more things you do with the data once it is in the system, the more cost effective it becomes. For example, if it costs $1,200 to encode the topographic data on a 7 1/2' quad and then it costs $800 to composite and display a slope map, the total cost of that map is $2,000. If, however, the same data file is also used to do a view study, a series of perspectives, an aspect map, earthwork analysis, cross sections and a drainage map, then the cost of encoding can be amortized over several applications. The result could be that the effective total cost of the slope map is $900 instead of $2,000.

CONCLUSION

The utilization of a good, proven system is cheap. It's the development of a new system that is expensive. If you clearly perceive your role in the area of GBIS's as that of a user, you can afford it. If you perceive your role as that of a developer, you will have difficulty and will probably never be able to justify your cost.

ECOSYM: A Classification and Information System for Wildland Resource Management[1]

J. A. Henderson

L. S. Davis[2]

Abstract.--ECOSYM is an approach to classifying wildland ecosystems by ten basic components (Bedrock geology, Regolith, Elevation, Slope, Aspect, Temperature, Precipitation, Soil, Current Vegetation and Potential Vegetation) and an information handling and delivery system which uses this classification both in the data acquisition and data retrieval stages. Management information is related to the classification by "rules" and is accessible either in quantitative format or as maps. Integration of the basic components occurs at the management or decision-making level rather than being structured into the basic classification.

INTRODUCTION

As more people demand more from the nation's resources, more intensive and sophisticated management of wildland becomes necessary. Sophistication, in turn, requires better information.

The National Environmental Policy Act of 1969 (NEPA) specifically requires evaluation of resource development impacts ranging from sediment yields to visual values.

The Resource Planning Act of 1974 (RPA) requires a quantitative assessment of the nation's 1.8 billion acres of wildland resources to determine current status, production potentials for all renewable resources including timber, range, water, recreation, fish and wildlife.

The National Forest Management Act of 1975 (NFMA) calls for land management planning which can spatially and temporally consider the explicit production and interaction of all forest outputs.

Many of these assessments and evaluations, while legally required, are things for which we simply don't have adequate knowledge and present information systems are not adequate for the task.

Our objective was to examine wildland resource classification at its most fundamental, conceptual level and to propose, if possible, a general strategy or framework for classifying wildlands which would meet the needs of resource managers and planners from local to national levels. Early on it became apparent that classification was simply a means to an end--the development of wildland management information systems. We therefore expanded our work to consider how an information system might work more effectively, and ECOSYM is the result.

A more detailed discussion of this concept is also available.[3]

NEEDS AND CRITERIA

Information about wildland resources is one of the most pressing needs of managers. Among the most serious problems mentioned by wildland

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[3]Henderson, J. A., L. S. Davis and E. M. Ryberg. 1977. ECOSYM: A classification and information system for wildland resource management. Department of Forestry and Outdoor Recreation and Davis, L. S. and J. A. Henderson. 1976. ECOSYM: A classification and information system for management and wildland ecosystems - Progress Report 1, Department of Forestry and Outdoor Recreation. 55 p.

managers in a recent survey was the lack of adequate multiresource data bases and methods for assessing potentials and impacts to aid in local planning. Also lacking were methods to expedite getting research results to the managers who could make use of them. Among other things, wildland resource managers wanted information on:

- --state variables such as timber productivity, wildlife habitat, range suitability
- --process variables such as rates of soil erosion, impacts, plant succession, water yield
- --probabilities of events such as regeneration, success, mass failure, insect outbreak
- --area and extent of resources and resource attributes
- --expected treatment responses for both state and process variables.

Typically, each time a question comes up, the manager collects or estimates information specific to that question. Once used, little thought is given to saving this information for similar questions coming up later. The pace at which land management decisions are made today precludes this casual approach to problem solving and information management, especially when information gathering funds are limited. Moreover, because managers are being held more accountable for their decisions, better and more sophisticated information is needed for support.

We have determined that to meet today's and future needs, an information system should satisfy the following criteria:

- --It must be capable of dealing with a broad range of questions and problems.
- --It should treat the local land manager (National Forest Supervisor, National Park Superintendent, or Bureau of Land Management Area Manager) and his staff as the primary clients but be so structured that the information is also available to regional or national managers as well.
- --It should be open-ended so that components may be added to it through the course of updating and improvement.
- --It should incorporate existing information and technology as much as possible.
- --It should be efficient in terms of providing information at the lowest cost per unit.
- --It should be professionally credible based on conceptual and empirical tests.
- --It should use straight-forward logic and language suitable for the nontechnician.
- --Its logic and structure should be compatible with computer-based data handling systems.

The system we present in the following pages has been developed with these criteria in mind. ECOSYM is a start toward an integrative wildland resources information system. It is fittingly open-ended and amenable to updating and improving as new technologies become available, new questions arise, and newer answers are needed for old questions, for no question about wildland resources management is every satisfactorily answered once and for all.

THE ECOSYM CONCEPT

ECOSYM is a system for classifying and storing data about land and natural resources and a way to relay useful information to the manager. ECOSYM generates management information through a two-stage process. First land-resource base is classified according to the ECOSYM classification framework. Second, these classifications are objectively combined, integrated, manipulated and/or evaluated by a set of "rules" to produce the desired information.

The Classification Framework

The basis of the ECOSYM approach is a framework of ecosystem component classifications that are hierarchically structured and objectively defined. It is a component framework in that it addresses each recognizable bio-physical element of the ecosystem separately. The ECOSYM framework includes systems for classifying bedrock geology, regolith, topography, climate, soil, current vegetation and potential vegetation (Table 1).

These classifications are place independent. That is, you don't have to know where a unit, site or ecosystem is or what is adjacent to it in order to classify its components.

The physical characteristics of a component are the criteria used in ECOSYM classifications, rather than the geographical location of a particular unit. For example, two bedrock units which exhibit the same physical characteristics are classified in the same class even if one is located in Florida and the other in Alaska.

Each component is classified in a hierarchical structure with different levels of generalization and resolution. The structure of a hierarchical classification is arranged, where each higher level in the classification is an aggregation of those and only those classes or types in the levels immediately beneath it. The classes become more and more homogeneous as lower, finer, more detailed levels of the hierarchy are used.

Each ECOSYM component classification system is designed to facilitate objective application.

Table 1.--The ECOSYM Classification Framework: Hierarchical Level with Illustrative Class Names

BEDROCK GEOLOGY	REGOLITH	TOPOGRAPHIC			CLIMATE		SOIL	CURRENT VEGETATION	POTENTIAL VEGETATION
		ELEVATION	SLOPE	ASPECT	TEMPERATURE	PRECIP.			
Order (Igneous)	Order (Deposit-ional)	Megarelief (nearest 1000 feet)	Megaincline (nearest 10%)	Megadirection (90° segments)	Megatherm (nearest 10° C)	Megaprecip. (nearest decimeter)	Order (Mollisol)	Physiognomic type (Forest)	Physiognomic type (Forest)
							Suborder (Boroll)	Formation (Subalpine forest)	Series Group (Subalpine forest)
	Class (Colluvium)								
Suborder (Coarse-crystalline)		Macrorelief (nearest 100 feet)	Macroincline (nearest 1%)	Macrodirection (45° segments)	Macrotherm (nearest 1° C)	Macroprecip. (nearest centimeter)	Great Group (Cryoboroll)	Cover type (Abies lasiocarpa)	Series (Abies lasiocarpa)
	Type (Fall-Talus)								
							Subgroup (Typic Cryoboroll)	Community type (Abies lasiocarpa/ Berberis repens)	Habitat type (Abies lasiocarpa/ Berberis repens)
Class (Granitoid)	Locale (Rainier Ash)	Minirelief (nearest 10 feet)	Miniincline (nearest .1%)	Minidirection (22.5° segments)	Minitherm (nearest .1° C)	Miniprecip. (nearest millimeter)	Family (Fine Mixed)	Phase (-Symphoricarpos oreophilus)	Phase (-Symphoricarpos oreophilus)
							Series (Kings Peak)	Condition Class	
Type (Quartzolite)	Conditional Series - applies to any level	Microrelief (nearest 1 foot)		Microdirection (nearest 1°)			Pedon	Community	Community
								Sample	Sample
								Site	Site

This results because the classifications are based as much as possible on quantifiable and measurable parameters. This means that the user will be able to classify a component by evaluating specific criteria rather than by making subjective interpretations.

Classified components can be represented by the symbol:

$$E_{ijk}$$

where

i = the component
j = the hierarchical level or level of resolution
k = the named classes

In the case of the classifications of topography and climate, which represent continuous parameters, the hierarchical levels merely represent finer or more general resolution (for example, four hierarchical levels describe elevation, 1) to the nearest 1,000 feet, 2) to the nearest 100 feet, 3) to the nearest 10 feet and 4) to the nearest 1 foot).

Within each hierarchical level there are named units or classes (the Spendlove Soil Series, the Ashley Soil Series and the Kings Peak Soil Series) represented by the symbol k. Using Table 1 to illustrate, if a site was classified as $E_{10,4,1}$, this would mean the current vegetation (the 10th component) has a cover type (4th hierarchical level j - 4) of subalpine fir, *Abies lasiocarpa* (which is the first named class k = 1). We have not (and could not) finish filling the matrix of names and levels of ecosystem components since it is a concept of worldwide applicability and each locality or geographic area will have to develop keys and field procedures to name the local classes (k). This is a task that may take many years. What ECOSYM provides is the structural framework for such a classification and the beginnings of identifying its elements. The components are purposely kept separate and as "clean" as possible. Integration of components is an important activity but we feel is best done by the manager with his objectives in mind rather than by the designer of the system. This will yield more flexibility and lend itself to answering more questions in the long run than a system which is integrated from the beginning and is therefore fixed. A brief description of each component classification is presented below; the details of each are found in Henderson et al., (1977).[3]

THE ECOSYM COMPONENTS

Bedrock geology (E_1)

Bedrock is the coherent material which makes up the surface of the earth. It is not readily rippable or eroded and may occasionally crop out at the surface.

Bedrock classification is based primarily on origin, grain size and shape, crystal size and orientation, and mineral composition including cements of the material.

Bedrock classification has four hierarchical levels. The highest, most generalized level is the Order, (igneous, sedimentary, and metamorphic) followed by Suborder, Class, and Type. In addition to the above subdivisions, site specific information concerning the bedrock is described by the Conditional Series.

As with all ECOSYM components, mapping proceeds by means of a defined mapping rule which combines similar contiguous classified points.

Regolith (E_2)

Regolith is the loose, fragmented, poorly consolidated surficial material overlying coherent bedrock. The regolith classification is based on structure and the formative processes responsible for creating, transporting and depositing the surficial material.

Regolith is the "Parent material" from which the soil (E_8) is developed. In this classification approach "soil" is usually limited to the upper, modified layers of regolith. Although for shallow soils, the two may be closely synonymous. Like all ECOSYM classifications, regolith is classified as discrete points or columns through the profile to bedrock. The areal extent of regolith or surficial features with areal dimensions such as alluvial fans or glacial moraines are not recognized in the classification. They become recognizable as units only after a map is made based on the classification.

Regolith classification has four hierarchical levels (Table 1). The most generalized level is the ORDER. After Order are CLASS, TYPE and LOCALE. In addition the CONDITIONAL SERIES is used to describe the thickness and vertical composition as applied at any hierarchical level.

Topography (E_3, E_4, E_5)

Topography is the relative positions, including elevation, of the features of the landscape. We utilize three attributes of topography, i.e., elevation, slope and aspect, as basic components in ECOSYM. Terrain descriptions or physiography are integrations of topographic attributes and the physical geography of an area.

The products of such integrations are maps, while as a classification we deal initially with

slope, aspect and elevation as point attributes at a location.

Each attribute is arranged in a hierarchy of resolution based on precision of measurement. Each component defines a point by a numerical value at the appropriate level of resolution. Although different units of measure may be employed, presently elevation is in feet (meters), slope is in percent and aspect in degrees.

The hierarchical nature of a topographic classification may not be necessary or appropriate for all uses but such a structure is developed so that it will best fit into the overall ECOSYM framework.

Climate (E_6, E_7)

Climatic variables are very important factors in the structure of ecosystems and in the processes that drive them. However, these same climatic variables are extremely difficult to measure or even estimate for most areas under natural resources management. Two variables, total annual precipitation and mean annual temperature, were included in the ECOSYM classification system. Others may be used or included at a later date. Each climatic element is arranged in a hierarchy of resolution based on precision of the estimate similarly to the topographic classification, with precipitation in inches (mm) and temperature in degrees Fahrenheit (Celsius). It may not be necessary or appropriate for all uses to arrange climatic variables into a hierarchy but such a structure is developed so that it will fit into the overall ECOSYM framework.

Soil (E_8)

Soil is the modified upper portions of the Regolith (E_2). The soil classification system we use is published in Soil Taxonomy, by the Soil Conservation Service Staff in 1975. Soils are identified in the field based on their morphological characteristics. These field data, together with data from laboratory analysis, permit classification of soil pedons and the preparation of soil maps.

Since soil is very much a product of the vegetation and climate working on the parent material of the regolith, it appears to be impossible to disregard these influences in classifying the soil. Because the classification system is already in widespread use in the United States we conditionally accept the approach proposed by the SCS.

Current vegetation (E_9)

The current vegetation occupying the landscape is classified according to a new vegetation classification system. This "new" system, however, is mostly a synthesis of aspects of existing and/or already published approaches. The classification hierarchy applicable in the United States and Canada uses Penfound's Physiognomic type, slightly modified, as the broadest unit. Physiognomic types are separated into "formations" in the sense of Braun-Blanquet. Formations are divided into cover types similar to the concept developed by the Society of American Foresters, but applied to all vegetation rather than just forests. Cover types are subdivided into community types which is in common usage in the western U.S. and was derived from the older term "Association" which is mostly used in Europe today to indicate a similar classification unit. Community types are subdivided into phases and described by condition class. Such a current vegetation classification system appears to be the best compromise of existing approaches for the purposes of providing a wildland resource data base and management information system.

Potential vegetation (E_{10})

The basic attributes of a site combine to create an environment to which one and only one climax plant community is adapted. A classification of land based on the potential of the land to support a particular kind of vegetation is used as a basic classification of land resources. This approach is based on the work of Daubenmire and his "habitat types" although it is influenced and modified by Küchler's extensive surveys and maps of potential vegetation and is also modified to accomodate the "range site" used by the Soil Conservation Service. Six hierarchical levels are proposed: 1) Physiognomic type, 2) Series group, 3) Series, 4) Habitat type, and 5) Phase as used and described by Daubenmire, Pfister and others.

RULES--THE INFORMATION DELIVERY SYSTEM

The classification framework provides a means of identifying and describing wildland resources. The function of this framework is to provide the basic data from which useful management information can be generated. ECOSYM uses the symbol "Y" to represent this information. A fundamental hypothesis of the ECOSYM concept is that discernable and explicitly quantifiable relationships exist between component classes (E_{ijk}) and information needed by managers (Y). In the terminology used by ECOSYM these relationships are called rules. These rules might be thought of as models, equations or algorithms. The general form of a rule is:

$$Y = f(E)$$

Rules (f) are processes for transforming the component classifications of an ecosystem

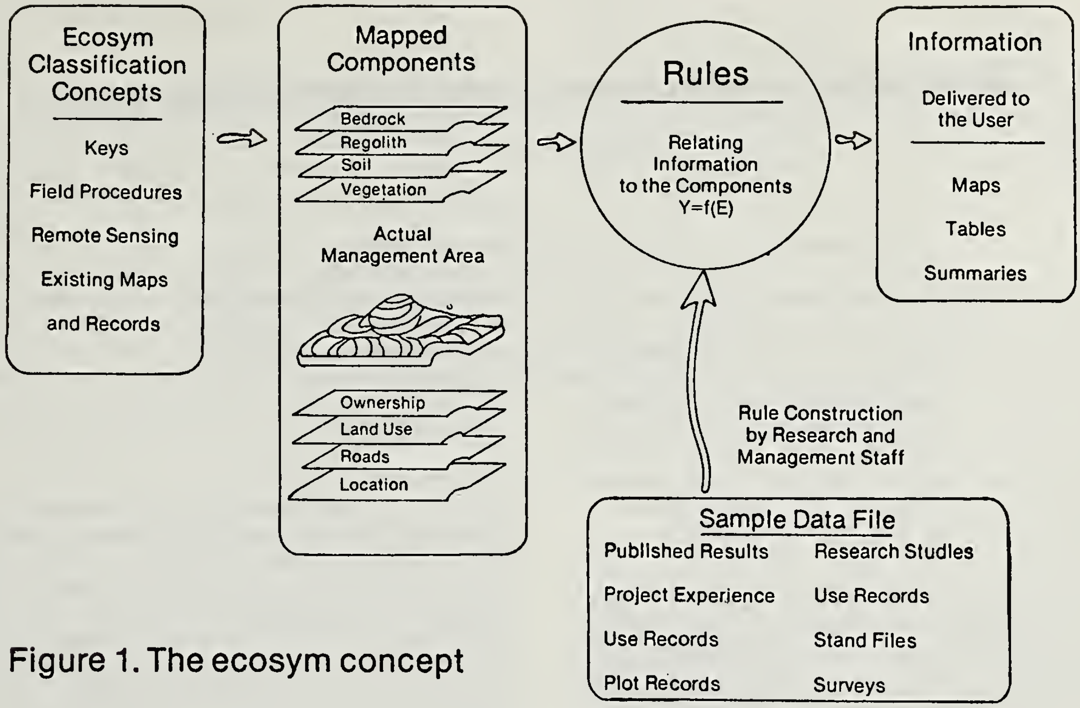

Figure 1. The ecosym concept

(E_{ijk}) into information (Y) that can be used by managers. Rules vary in complexity from simple associations which utilize only components as data inputs to complex integrations and interactions which may use other external data inputs in addition to the components.

Rules are an important link between component classes and usable management information. Each rule requires that a program of development and testing be carried out. Once developed, however, rules may be utilized over and over to predict, rather than measure, the information needed by managers.

For example, a rule has been developed for predicting annual forage production for areas encompassed by the Price Ranger District of the Manti-LaSal National Forest. The form of this regression based rule is:

$$Y = b_o - 1.291\ X_1 + .04297\ X_2$$

where:

- y = total dry weight of herbage in grams/sq. ft.
- b_o = a cover type intercept that ranges from -130.8 to -328.59 depending on cover type
- X_1 = slope in percent
- X_2 = elevation in feet

This rule may be used to predict annual forage production on various sites on this ranger district simply by inputting the appropriate variables, all of which are to be provided by the ECOSYM data base.

The concept of the rule has many applications within the ECOSYM framework. The principle use of the rule is to predict management information based on component classification classes. However, the same rule principle can be used to predict or analyze between-component relations. For example, predictions of cover type from topographic and regolith components is one possible such use.

ECOSYM uses this approach to predict climatic components (precipitation and temperature) from topographic components.

To summarize, the central elements of the ECOSYM concept and procedures as they would be applied are illustrated in Figure 1. Using the component classification approach, a selected set of components on actual management area are classified and mapped. These are coupled with other mapped information such as ownership to form the basic data set. Then, a wide variety of sample data from research and administrative records which has also been stratified by the ECOSYM components is assembled and used by research and administrative staff to construct rules which relate desired management information to the components. The rules are then used to operate on the component data base for the management area to provide the manager with processed information in mapped or tabular form.

Integration of Data Information Between Agencies[1]

R. Eugene Wunderlich[2]

An index file has been established in Denver to provide a reference to the availability of data information. This is an automated file that can be accessed by remote terminal. The purpose of the file is to provide a simple and quick location of where to find certain kinds of data information. Although the initial file is small the need is large to establish this kind of file.

The Need -- A Method -- More Support

The Need

Data automation is not new, however, many agencies are just coming into their own in the last 10 years. By this, I mean that the majority of agencies (whether they be Federal, state, or local) have established and developed their own way of automating their needs. In the process of developing their needs, each agency pretty much did their "own thing" in devising systems and writing programs irrespective of what may already exist in another agency.

In one instance we are duplicating our work by collecting like or similar data from essentially the same area. An example of this may be a wildlife habitat survey that could be done by BLM. The Fish and Wildlife Service could include the same area in a regional analysis which is followed by a State Game count inventory. All of this work could have reasonably been accomplished by one effort.

Still another example that carries an extensive duplication is in Social-Economics. Basically all information that is used for socio-economic analysis comes from the Bureau of Census and Department of Economic Analysis. I know of at least five federal agencies that have developed systems and written programs to achieve very similar analysis.

The use of equations, formulas, computations or "whatever" are compatible items that have use by many agencies. These are generally available through research papers or other media. However, to automate the use of an equation a computer program must exist. After an initial program, for a particular equation has been written, it can generally be used on other computers with minor revisions. With all other factors remaining the same, the reuse of the initial program would save countless dollars in not having to write, compile and test the program again.

Range Management uses many formulas in calculating; vegetation volumes, carrying capacities, livestock manipulation and others. Forestry Management manipulates volume equations, basal area computation, and others, all of which are common tabulations for given areas. Therefore, if the whereabouts of these computations was easily available, considerable time and expense may be saved by not having to duplicate the effort.

A Method

More than one year ago, upon getting an assignment to find out where and what kind of Resource data and computation formulas were available, I discovered that many people were interested in finding the same kind of information. I set up a meeting of these interested people which involved some twelve (12) agencies.

Realizing the need to establish a "clearing" or "referral" center for data information we established an informal organization called the "Data Exchange Forum." The objectives of this group are basically three fold: (1) to meet and exchange ideas on automated procedures, methods, and information, (2) to establish a computerized interactive telecommunication system in order to index data information, and (3) to encourage agencies to input into the system and at the same time to find a "home"

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[1]Paper presented at the Integrated Inventories of Renewable Natural Resources - National Workshop, Tucson, Arizona, January 8-12, 1978.

[2]R. Eugene Wunderlich, Resource Systems Specialist, Bureau of Land Management, Denver Service Center, Denver, CO 80225.

for the update and maintenance of this index system.

Meetings of the Data Exchange Forum are held bimonthly at the Denver Federal Center. They involve a guest speaker followed by a general group discussion. The meetings are open to all Federal, state, or local government employees.

The data index file is established and data information is being input into a CDC CYBER 70 computer at the Bureau of Reclamation. Access to the data file is by an interactive telecommunication terminal. The information is available to anyone with a proper charge code and the knowledge of the access procedure.

The information that is put onto the data file is not raw data, but information as to where the data may be obtained. The format of the file consists of an abstract of 1000 characters to explain the type of data, a list of keywords that pertain to the subject, the name of the agency that has the data, and the name and phone number of a person that can be contacted for more information.

Upon accessing the data file, information may be obtained in a variety of ways. A print of the first line or each entry may be obtained from part or all of the file. Through the use of keywords, entries may be selected by agency, by subject types, or by data types.

As I have already implied, the use of this data file is limited only by your imagination. As the size of the file expands, I suggest the following uses are available:

1. Determine the location of data information pertaining to a particular subject.
2. Search for certain data that may have already been collected by another agency for a particular area. This could save an expense of duplicate collection of the same type of data from the same area.
3. Another benefit could be the location of a program that manipulates data based on a particular formula. The program itself may be obtained or you may find someone willing to allow your data to be run through their facility.

More Support

To date we have 400 entries on the data file. Since it has been difficult to get agencies to input their own data, I have been inputting most of the entries. I am using catalogs, dictionaries, and other hard copy material as a source of input. I am, however, getting into a position where I cannot allow my personnel the time to continue this work.

I have contacted many individuals and executive groups; librarians and record managers; computer analysts and technicians. Some of these included Mr. Robert Sanchez, Special Assistant to the Secretary of Interior and Mrs. Mary Hufer, Librarian for Natural Resources Library in Washington, D.C. I was also interviewed by four congressmen from a House Appropriations Subcommittee. In every case there has been considerable enthusiasm for the need of this effort. To date no decision has been made toward the placement of this function into any particular organization.

From now and until a "home" might be found for this data file we intend to keep it active and to add to it as time permits. Any effort that can be given by you or by your agencies toward inputting data information to this file, would be appreciated.

If you would like more information or would like to know how to access this file call me on FTS 234-2083.

Panel IX—State of the Art: Moderator's Comments[1]

Vernon J. LaBau[2]

Abstract.--A summarization of the current status of integrated multiresource inventories with emphasis on planning, techniques, land classification systems, remote sensing, data processing and mapping. The state of the art is pictured as a collage of many different objectives, techniques, and methodologies. Emphasis is placed on cost evaluations.

The intended objective of Panel 9 in this workshop was to present several viewpoints on the state of the art of integrated inventories of renewable natural resources. The objective of this paper is to present a general overview of what that state of the art is. That is not to imply a summarization of the Panel 9 papers. Some of the papers in Panel 9 are less to the point of the state of the art than others because of their limited nature. Some of the papers in Panel 9 are international in scope to broaden the perspective in that dimension.

The state of the art of integrated inventories of renewable natural resources is not easily described. Actually, the state of the art appears as somewhat of a collage of ideas, procedures, and methodologies, often leading in different directions. The reason for the differences in direction can be attributed to the functional (singular resource) needs and objectives of natural resource inventories in the past. This is not intended to be a critical statement, but simply a statement of fact. Many of the papers already presented in this workshop support that image. The papers presented by the members of Panel 9 do not deviate from that collage image.

[1]Paper presented at the Integrated Inventories of Renewable Natural Resources, A National Workshop, Tucson, Arizona, Jan. 8 - 12, 1978.

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To cover the full spectrum of the state of the art, it is important to summarize from other panels as well as from Panel 9. Beginning with Panel 1, but also in later panels, several speakers mentioned the need for careful objective and goal-setting evaluations in the early planning stages. Information needs are sharpened and attributes to be measured are clarified. The need to assess interactions between resources, and relative to resource uses, amplifies the importance of clarifying objectives in the goal evaluations.

It is very important that goals and objectives be evaluated at a high enough decision level that one is really evaluating program needs, and not getting bogged down in specifics of techniques and methodologies. This may involve evaluating state and federal natural resource legislation (such as the 1974 Resources Planning Act, 1976 BLM Organic Act, the 1977 SCS Soil and Water Act) to determine program implications. If applicable, this level of input is then kept in mind by the multiresource manager in setting goals, objectives, and determining information needs.

One of the best ways of determining if the inventory is doing what you want is to prepare a set of the proposed information summary tables that can be presented from the data collected. Then ask the question, "Do these tables meet my needs as a multiresource manager in terms of assessing interacting resource uses as well as singular resource use?" If not, more time should be spent evaluating and clarifying goals, objectives, and information needs. There seems to be a healthy trend toward spending more time in the "goals/objectives/needs" evaluation phases of inventory.

With respect to current resource inventory techniques (Panel 2), again it seems that a collage of techniques exists. One wonders if it is really possible to pull together this diversity of methodologies and procedures in a manner to assess the various resources in a truly integrated inventories system. The general consensus is that much needs to be done to get a common system working smoothly. However, there are indications of a commitment on the part of resource managers to obtain operational techniques for integrating inventories. As more understanding is obtained about what is common among the various resource inventory objectives, we should find it easier to reach something of a consensus.

One way of improving the communications between functional specialties is to establish a point of agreement, or at least an understanding, with respect to standardization of techniques. It may be too much to expect that one universal integrated inventory technique would be accepted as standard. However, we should standardize data collection techniques, data bases, and inventory processes, enough to be able to crosswalk data, analyses, and uses within and between user systems. There seems to be an encouraging trend in that direction, but much remains to be done.

My comments on the need for integrating inventories (Panel 3) have already been summarized in my comments on Panel 1. Resource managers are generally recognizing this need as a mandate--a very good sign.

Another barrier to improving the state of the art is functional terminology. Even when we think we are speaking the same language, it is sometimes hard to understand what an inventory person from a closely related resource inventory system is saying. A critical tool for breaking down this barrier is a generally accepted land, aquatic, soil, and vegetation classification system. This implies generally accepted definitions in each of these systems. Agreement on definitions is the key to overcoming this communications barrier. Historically, these classification systems have usually not been developed with interaction capabilities in mind, but more often as ends unto themselves.

Again, it is not reasonable to expect that all resource inventory systems managers will accept one classification system to be applied across all users needs, any more than one would expect to standardize to one set of goals and objectives across all inventory systems. However, the more resource inventory people and data users can agree on classification concepts, the sooner we can bridge the problems of assessing resource use interactions. The state of the art is benefiting from a trend in that direction.

The panel presentations on remote sensing were colorful to say the least. They were also very interesting and useful.

I first started using aerial photogrammetry about 20 years ago under the influence of Karl Moessner, Bob Pope and others who received their photo interpretative grounding during World War II. At that time, aerial photogrammetrics was going thru the panacea syndrome. After many dead end encounters in trying to overextend the use of aerial photos in resource management, reality prevailed and aerial photos became accepted as a good resource inventory tool, but with definite limitations.

Remote sensing--use of satellite imagery and high altitude color infrared photography, etc.--evolved thru a similar "user growing pain" process, and now we are accepting the fact that remote sensing can't do everything we first expected. But here again, this is a powerful tool when used within its limits. We still have some distance to go to know what some of those limits are. That is an exciting and challenging area that is improving at a computer age pace.

Panel 6 looked at sampling designs and methodologies. A healthy and stimulating diversity of procedures points in many different directions. We have heard presentations on some interesting extensions of applications to basic sampling methodologies. For example, one aspect gaining acceptance among inventory people is post stratification. This is especially true where samples are taken from systematic grids.

One important state-of-the-art feedback that I have encountered is that biometricians are emphatically saying that new sampling designs are not necessary. We need only modify existing methodologies to meet the challenge of estimating all renewable resources and their interactions.

As so many mentioned before in this workshop, the key to integrated inventories is clearly stating and defining our goals and objectives in terms of singular and multifunctional information needs. The real challenge is in identifying the information needs to assess interactions. Once that is done, existing sampling designs can be adapted to assess the resources and their interactions. Granted, there will probably be additional evaluation of sampling properties, expectations, etc. to look at designs and methodologies in terms of estimating interactions, but this is not an insurmountable problem.

One aspect of the sampling design evaluations sorely needing study involves cost effectiveness. Because of the tremendous expense associated with multiresource inventories, there is a pressing need for cost effectiveness evaluations of applicable sampling designs. It may be proven through these cost effectiveness studies that a well planned multiresource sampling design is less expensive than the many different singular function resource sampling designs now used which provide little or no resource interaction assessment capabilities.

Panels 7 and 8 on data processing and information systems highlighted the role of computer and data-processing systems. Progress is being made at a computer-age pace.

The key to successful data processing and computer mapping, of course, is a good data base management system (DBMS). The speakers presented a number of separate programs, some of which could be brought together in an integrated inventories DBMS. This DBMS concept is critical to a successful integrated inventories system. We must be careful to know what the underlying assumptions of the separate programs are prior to bringing them together so we don't create a "black box" monster that doesn't fit into the resource inventory goals/objective/needs context.

We do need to look at extending data analysis and tabulation capabilities of existing systems in terms of displaying interactions and their reliabilities.

It is not possible to overemphasize the importance of data credibility. That credibility is dependent upon a long chain of factors ranging from sampling methods and techniques thru field team training, attitude, and abilities. Data credibility must be kept at the highest possible level. Computerized data editing systems are contributing significantly to this credibility and adding integrity to the state of the art.

It is when we begin to look into the area of resource mapping that the importance of being able to attain, analyze and describe different pieces and types of data simultaneously becomes apparent.

The importance of "in-place" responsive inventory systems has placed increasing emphasis on map or coordinate-oriented data recall capabilities. There is no question that mapping, polygon, or coordinate base recall systems are going to be used - if users can get by the cost barrier. Some good "mapping" coordinate systems have gone "by the boards" because of cost, even within the federal government. Many methodologies that are available are usable, but expensive. We have to either overcome budget limitations or find less expensive methodologies.

As we extend into the Data Base Management System, the potential integrated inventories will be greatly expanded. Considerations for increased costs and higher levels of expertise must be evaluated.

From a field-oriented resource inventory viewpoint, I feel there is one indicator that will reflect when we have finally arrived at a point in the state of the art that will result in highly credible output. That indicator is: the replacement of one- and two-man field teams with three- to four-person multidiscipline field teams for data gathering. The traditionally used teams of one or two people cannot carry the level and diversity of multiresource expertise necessary to correctly assess the various data attributes and interactions needing field evaluation.

Two alternatives to increasing field team sizes that are sometimes proposed are: (a) employ highly skilled, well-paid professionals on two-person teams with access to continual on-site guidance and training from multidiscipline experts, and (b) simplify data collection procedures to collect selectively objective data; and, in turn, strengthen data analysis capabilities, to get more interdisciplinary mileage from the basic data, thus requiring fewer multidisciplinary skills in the field teams.

I am sure there are other indicators that are more meaningful from other viewpoints, but this, in my opinion, is one of the critical checkpoints.

James Mullen (Panel 2) in his paper noted "there are always more problems, particularly in a holistic approach than there are time, money and bodies to solve them." Most multiresource managers will be required to think in terms of committing more bodies, time, and money to this effort, realizing that we will never have all of the information needed to solve all of the problems. But hopefully, we can do a continually better job of solving some of the problems.

In conclusion, I feel the state of the art is advancing in all areas of integrated inventories of renewable natural resources. Much remains to be done in all areas. There is promise of some costly systems in the future. But, the benefits from, and needs for, these integrated inventories are such that the resource community is mandated to respond in the most professional manner possible.

A Multifunctional Inventory Approach to Multiple Use Analysis[1]

Peter F. Ffolliott[2]

Abstract.--To insure that land management practices do not adversely affect the environmental complex, direct measurement of all natural resource products and uses is desired. However, when direct measurements are not possible, a multifunctional inventory can be synthesized for multiple use evaluations using pertinent research findings. To choose the best land management practice from a number of alternatives, it is necessary to know the present and future natural resource products and uses, the direct benefits and costs, and the suitability of a tract of land. Care must be exercised when selecting the research findings that will be used to make indirect estimates.

INTRODUCTION

Increasing demands placed on natural resource products and uses (timber, water, forage for livestock, wildlife habitat, etc.) require land management practices that provide flows of satisfactions without adversely affecting the environmental complex. Knowledge of potentials for the utilization of all natural resources available to furnish combinations of products and uses is required to insure the development of effective multiple use management practices for the total resource mix.

Mensurationally, knowledge of utilization potentials of natural resources ideally involves the direct measurement of all products and uses. This approach is feasible if measurement techniques and sampling procedures are available and operational. Unfortunately, this is not always the case.

Estimating forage for livestock, for example, is often hampered by measurement and sampling problems. Measurements of forage are frequently based on relatively small plots (Goebel et al. 1958, Pechanec and Pickford 1937, Shoop and McIlvain 1963) which conceptually, approach point measurements; furthermore, these measurements may be biased (Smith 1968). In addition, population variances may be quite large (Clary 1969, Lyon 1968), creating sampling difficulties.

Obviously, when direct measurement of natural resource products and uses is not feasible, alternative mensurational techniques and procedures are necessary. One alternative to direct measurement, the approach to be discussed in this paper, is to design an inventory that takes advantage of available research findings which show natural resource products and uses for different land conditions, productivities, and management practices. An advantage of an inventory of such a design is that, quite often, products and uses that are difficult to measure or sample directly can be estimated from inventory-prediction variables that are either readily available or easily obtained. These relationships, when coupled with appropriate sampling procedures, may provide sufficient knowledge of potentials for the utilization of natural resource products and uses not easily quantified by direct means.

In addition to reducing measurement and sampling problems, an inventory of the above design may be planned and executed as only one sampling exercise over a tract of land, rather than separate (and discrete) inventories of differing mensurational techniques.

The general thesis to be developed in this paper is that a multifunctional inventory can be

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[1] Paper presented at a National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.

[2] Professor, School of Renewable Natural Resources, University of Arizona, Tucson.

synthesized for multiple use evaluations through applications of pertinent research findings. For illustration, a multifunctional inventory of a particular forest ecosystem will be described; but, similar conceptual developments can also be formulated in other ecosystems. Specific relationships between natural resource products and uses that are difficult to measure and direct measurements of forest overstories (which are relatively easy to obtain with standard mensurational procedures) will be highlighted. It is not the intent of the paper to indicate statistical expressions of aggregate sampling error or to suggest necessary sampling intensities and designs, however,

In many respects, this paper is a review and update of earlier investigations of natural resource inventories aimed at multiple use evaluations (Clary 1964, Ffolliott and Worley 1965, Worley 1966, Barger and Ffolliott 1970).

INVENTORY OBJECTIVES

Requisite to designing a multifunctional inventory for multiple use evaluations is the identification of the inventory objectives. In general, the central objective of such an inventory is to provide information about a tract of land so that one or more best land management practices can be chosen from among an array of possibilities (Worley 1966).

To achieve the above goal, three sets of information (Worley 1966) are generally required as a basis for making the choice: (1) information that provides a basis for estimating present and future natural resource products and uses; (2) information that gives a basis for estimating direct (and immediate) benefits and costs associated with implementing the management practices; and (3) information that is required to ascertain the suitability of a tract of land for the proposed management practices.

Multiple Use Evaluation

While foresters are commonly involved with estimating the growth and yield of standing timber, similar determinations are necessary for other natural resource products and uses on a multiple use analysis (Worley 1966). Therefore, an objective of any multifunctional inventory is to obtain information which can be used to quantify, to the extent possible, the magnitude of the effects of implementing a management practice on all products and uses.

For the purposes of this discussion, the key element is to organize the inventory in such a way as to gather the source data that previous work has shown to be important with respect to applying multiple use relations based on inventory-prediction variables that characterize forest overstories. Close relationships have been identified between forage for livestock and forest overstories (Gaines et al. 1954, Halls and Schuster 1965, Ffolliott and Clary 1972), and between water yields and forest overstories (Hewlett and Douglas 1968, McConnen 1967, Brown et al. 1974). The particular forest overstory variable expressed in these relationships, as well as others, can advantageously be incorporated into the measurement instructions for an inventory to facilitate subsequent interpretation and solution.

Estimate of Benefits and Costs

Ideally, a multifunctional inventory needs to describe the natural resources on a tract of land in the biophysical terms found pertinent to estimating direct benefits and costs (Worley 1966). Where information is not available to calculate benefits and costs for the tract under consideration, the inventory should collect the necessary background for developing (or adjusting) benefit and cost research for local conditions.

Specific benefits from timber harvesting depends, in part, upon present and foreseeable markets. However, as market conditions often change quickly, and since these changes can affect benefits and costs directly, the inventory data collected should be flexible enough for interpretation under changing timber market conditions.

Similarly, the inventory should be designed to gather information about potential benefits derived from other natural resources (water, forage for livestock, wildlife habitat, etc.) with changing market conditions, rather than being restricted to generating statistics about products and uses currently marketable.

To identify costs of management practices, the inventory needs to quantify conditions on a tract of land in terms of those biophysical variables that have been shown relevant in measuring costs of implementation. As has been suggested in the literature (Miller and Johnson 1970, Turner and Larson 1974), these variables may include numbers, sizes, and spatial arrangements of trees, as well as physiographic features. Initially gathering biophysical source data and then coupling these variables with current dollar values, insures that estimates of costs are not dated.

Suitability Determination

It is important that the inventory be structured to provide data about a tract so that

determinations can be made as to the suitability of land management alternatives (Worley 1966). Regardless of what a specific management practice is to accomplish, the inventory must furnish information that will help to evaluate treatment potential and prescribe treatment feasibility.

Some of the questions which need to be answered include those which frequently confront foresters: What portions of a tract lend themselves to uneven-aged management; to even-aged management? On which areas does sawtimber occur at a basal area level considered the minimum for profitable harvesting?

In addition, questions relating to other natural resources may be asked. A range specialist may ask, "What portion of a tract is stocked in excess of a given basal area level considered the maximum to allow acceptable forage production?" A watershed manager concerned about increasing water yields might ask, "What is the extent of northerly sites covered by forest overstories dense enough for strip cutting to accumulate snow?" An economist interested in costs might ask, "How much of a tract needs to be treated, and to what intensity does the treatment need to be applied to bring the area to a prescribed stocking level?"

It should be seen that, to be effective, a multifunctional inventory must be planned to collect the information necessary to ascertain suitability for management within a multiple use context.

PLANNING AN INVENTORY

In many respects, a multifunctional inventory designed for multiple use analysis (and in particular, an inventory based upon relationships between natural resources that are difficult to measure and direct measurements of forest overstories) is comparable with a customary timber inventory in terms of procedure, but that more factors often need to be considered (Worley 1966).

Inventory Formulation

As with a timber inventory, formulation of a multifunctional inventory begins with an analytical flow chart which leads from the stated inventory obejctives through the required field and office procedures (Worley 1966). Perhaps the most important difference between these inventories is the care that must be exercised in selecting the specific research findings to be used in indirectly estimating natural resource products and uses from readily available or easily obtained inventory-prediction variables.

Alternative relationships may appear feasible in many instances as one works through the flow chart, necessitating an assessment of the ease by which inventory-prediction variables required for solution can be generated. In addition, alternative relationships may possess differing statistical precision and may demand unique measurement and sampling procedures which, once again, will require careful thought.

Sampling

As mentioned above, outlining the statistical methodology required in designing a multifunctional inventory will not be made in this paper. However, it should be noted that, regardless of how the sample is structured, it should be drawn so that it can be analyzed within a statistical framework (Worley 1966). In particular, it will be necessary to consider the propagation of errors in obtaining the desired estimates of the specified parameters to be inventoried.

In an illustration of the predicted outcomes of a multifunctional inventory that follows, the primary sampling unit has been defined as a point sample. Therefore, direct measurements of forest overstories can be obtained by standard point sampling techniques (Avery 1975, Husch et al. 1972). As multiphase sampling may also be employed in some instances, additional measurements are often taken to provide the linkage for dependent variables on a subset of the point samples. (Multiphase sampling is appropriate when information on a principle variable of interest is difficult and costly to obtain, while a secondary variable can easily and cheaply be observed.)

Multiple basal area factors may be used to improve descriptions of the spatial distributions of trees around the point samples. In addition, some of the available research findings used for multiple use evaluations indicate that the linkages are better defined with one basal area than with another.

PREDICTED OUTCOMES FROM THE INVENTORY

The predicted outcomes from a multifunctional inventory for use in multiple use analysis should include estimates of present and future natural resource products and uses, of direct benefits and costs, and of the suitability of proposed land management practices.

Perhaps the best way to illustrate the synthesis and predicted outcomes of a multifunctional inventory designed to estimate the responses of natural resources to land management

practices from applications of multiple use research findings is through a hypothetical example. For purposes of illustration, a 2,500-acre tract of unevenaged southwestern ponderosa pine forest land will be the area of concern. Furthermore, it will be assumed that a management practice aimed at reducing the present forest overstory density level of 150 square feet of basal area per acre by 50 percent (75 square feet) has been proposed. Therefore, the specific objective of the multifunctional inventory is to provide information about the tract of land so that decisions can be made with respect to the feasibility of implementing the proposed management practices.

Multiple Use Evaluation

For multiple use evaluation, the inventory must furnish information required to determine the effects of the proposed management practice on natural resource products and uses. Again, to illustrate, specific questions will be posed about various natural resources and will be answered for the hypothetical tract of land by combining research findings with inventory data. In essence, the inventory provides data about trees and their spatial distributions for present conditions, and then provides a basis for estimating answers to the same questions after a change in management has occurred.

The estimated responses of natural resources to management change can be expressed quantitatively or as a ranking (Worley 1966). Quantitative responses are often preferred, especially in this day of numbers and computers. However, ranked responses, which indicate the direction and perhaps the relative magnitude, may be more appropriate in some instances. Which form to use depends, in part, upon the multiple use questions posed and on the research linkages available.

As mentioned above, the multifunctional inventory to be illustrated will involve point sampling techniques. It will be assumed that the necessary number of point samples have been properly allocated to generate the desired sample.

Timber Management

Statement of Concern.--Reducing forest overstory density levels often immediately decreases forest growth per acre. However, individual tree growth rates may increase, so that eventually forest growth per acre may increase.

Problem.--What is the present forest overstory growth per acre? How is the growth affected immediately following and 10 years after implementing the proposed management practice?

Solution.--To determine present and post-treatment growth per acre, a stand table projection method of growth determination (Avery 1975, Husch et al. 1972) is applied to stand tables and diameter growth data from the inventory. Required of the inventory are: (1) present stand table and diameter growth; (2) post-treatment stand table to use with existing diameter growth data to determine immediate growth response; and (3) a projection of post-treatment diameter growth to use with the post-treatment stand table to estimate growth 10 years after implementation of the proposed management practice.

Source data for (1) and (2) are available directly from the inventory, while data for (3) will be based in appropriate research findings that describe changes in diameter growth with time.

Conclusions.--Presently, annual growth on the 2,500-acre tract is approximately 35 cubic feet per acre. Annual growth immediately after the proposed management change is expected to be 55 percent of the present growth, or 19.3 cubic feet per acre. Annual growth 10 years after implementing the proposed management practice should approach 80 percent of the present growth, or 28 cubic feet per acre.

Range Management

Statement of Concern.--Domestic livestock carrying capacity is dependent, in part, on the quantity of herbage produced. Research has shown that the production of herbage is determined to a large extent by the density of forest overstories.

Problem.--Estimate the present level of herbage production and show how the proposed management practice may change production.

Solution.--Empirical prediction equations that describe herbage production (the dependent variable, in pounds per acre) as a function of southwestern ponderosa pine forest overstories (the independent variable, in square feet of basal area per acre) have been developed for unthinned and thinned stands (Clary and Ffolliott 1966). These equations can be used to solve the stated problem.

To estimate the present level of herbage production, the equation for unthinned stands is used, with the independent variable equal to the present basal area level determined from the inventory. Herbage production under the proposed management practice is determined by applying the equation for thinned stands, with the independent

variable being the prescribed basal area level.

Conclusions.--Present herbage production is estimated to be 40 pounds per acre. Under the proposed management change, herbage production is expected to increase about 6 times, to 235 pounds per acre.

Wildlife Management

Statement of Concern.--The habitat of Abert squirrel, commonly found in southwestern ponderosa pine forests, is dependent upon different stand characteristics that reflect food, cover, and diversity components. Often, these characteristics are altered through land management practices.

Problem.--What is the present habitat quality for Abert squirrel and how is this affected by the proposed management practices?

Solution.--A system for rating habitat quality for Abert squirrel has recently been devised (Patton 1977). This system brings together information on food, cover, and diversity to produce a simple rating of habitat from poor to excellent. Ratings are based upon: (1) food — the occurrence of cone producing ponderosa pine and acorn producing Gambel oak (often found intermixed in southwestern ponderosa pine stands); (2) cover — basal area and stem diameter criteria; and (3) diversity — combinations of tree groups, dominance, and spacing.

Source data required to evaluate the habitat rating are essentially available from the inventory. If not explicitly included in the inventory, knowledge of interlocking crowns and number of tree stories is required

Conclusions.--The present habitat quality for Abert squirrel on the 2,500-acre tract is rated excellent, while the habitat quality under the proposed management practice will be rated as good. In terms of a ranked response, the habitat quality will decline.

Watershed Management

Statement of Concern.--Snowmelt is an important source of runoff from many southwestern ponderosa pine forests. Current research has demonstrated that the density of forest overstories may influence snowpack accumulation which, in turn, may affect the quantity of snowmelt runoff.

Problem.--How will the proposed management change affect the magnitude of snowpack water equivalent at peak seasonal accumulation?

Solution.--Inventory-prediction equations describing snowpack accumulation at peak seasonal accumulation (the dependent variable, in inches of water equivalent) as functions of southwestern ponderosa pine forest attributes (the independent variables, i.e., basal area, slope-aspect) have been developed (Ffolliott and Thorud 1972). Solutions of the appropriate equation will answer the question posed by the problem.

Present snowpack water equivalent (under average conditions) is determined by solving the equation with the present basal area level determined from the inventory. The anticipated posttreatment snowpack water equivalent (again, under average conditions) is estimated by applying the prescribed basal area level.

Conclusions.--By implementing the proposed management change, snowpack water equivalent at peak seasonal accumulation is expected to increase by approximately 1.7 inches.

Aesthetics

Statement of Concern.--Rising public concern for preserving aesthetic quality of wildland environments has required foresters to assess the possible impacts of proposed land management practices on scenic beauty. Several analytic techniques have been developed which provide opportunities for objective and reliable quantifications of public preferences for specific forested landscapes.

Problem.--Within the framework of a ranked response, how will the proposed management change affect the aesthetic quality of the 2,500-acre tract?

Solution.--Recently, a model has been synthesized to estimate public preferences for southwestern ponderosa pine forest environments from source data readily obtained from a timber inventory (Arthur 1975). This model describes aesthetic quality in terms of a scenic beauty estimate (SBE), a quantitative measure of public preferences for alternative land management systems (Daniel and Boster 1976). In essence, scenic beauty estimates (the dependent variable) has been empirically regressed against expressions of forest overstory density, size class distributions, and amount of slash (the independent variables). These regression equations can be used to determine a present scenic beauty estimate and to ascertain how this estimate may change as a result of implementing the proposed management practice.

To obtain a present scenic beauty estimate, independent variables generated from the inventory are used. A posttreatment scenic beauty estimate

(which is then compared to the present estimate to define a ranked response) is derived from inputs prescribed by the proposed management.

Conclusions.--As evaluated by scenic beauty estimates, implementation of the proposed management practice will cause aesthetic quality to decline.

Benefits and Costs

Theoretically, the proposed management change will immediately return money from the harvested primary wood products (sawtimber, pulpwood, etc.) and, possibly in the long-run, from an increase in grazing fees. It will be more difficult to realize direct (and immediate) monetary benefits from changes in natural resource products and uses not normally traded in the market place (water, wildlife habitat, etc.). However, the proposed change will also cost money, and these monies should be compared to costs of alternative projects to help decide on an ultimate allocation of funds.

By coupling physical data reflecting tree volumes to be harvested (determined, in part, by the multifunctional inventory) with monetary expressions of current stumpage prices and management costs, it is possible to derive estimates of direct benefits and costs that will be associated with implementation of the proposed management practice.

Benefits

Statement of Concern.--Availability of primary wood product market outlets will affect the direct benefits of the land management change being proposed. If only a sawtimber market is available, it is obvious that less monetary benefits will accrue than if both sawtimber and pulpwood markets were available.

Problem.--Calculate the direct stumpage returns associated with the implementation of the proposed management change on the 2,500-acre tract assuming: (1) only a sawtimber market is available, and (2) both sawtimber and pulpwood markets are available.

Solution.--A predicted stand table representing posttreatment conditions (as prescribed by the proposed management practice) is subtracted from the stand table indicative of present conditions determined from the inventory. The difference is then multiplied by the appropriate volume per tree values, weighed, and summed to obtain estimates of total sawtimber and pulpwood volumes that will be harvested.

While stumpage prices are generally localized for each logging chance, estimates can be made in terms of local prices and market conditions. For purposes of this illustration, sawtimber offerings are assumed to average $45 per thousand board feet, with pulpwood offerings about $1.50 per cord (or 75 cubic feet).

The product of the tree volumes removed by harvesting and current sawtimber and pulpwood stumpage prices furnishes a measure of direct benefits to be derived from the sale of primary wood products.

Conclusions.--The expected stumpage return on the basis of only a sawtimber market is $112.50 per acre, or $281,250 in total. With both sawtimber and pulpwood markets, the stumpage returns are about $117.45 per acre, or $293,625 in total.

Costs

Statement of Concern.--While the harvesting of primary wood products may give direct benefits, costs of thinning noncommercial trees and piling slash residues must be borne. These costs, in turn, will affect the benefit-cost ratio of the proposed change in management.

Problem.--What are the direct costs of precommercial thinning and slash piling on the 2,500-acre tract with: (1) only a sawtimber market; and (2) both sawtimber and pulpwood markets?

Solution.--Regression models that predict precommercial thinning and slash piling costs (the dependent variables, in dollars per acre) as a function of the amount of basal area removed (the independent variable, in square feet per acre) have been synthesized for operational applications in southwestern ponderosa pine forests (Turner and Larson 1974). Precommercial thinning costs are related to basal area removed noncommercially, while slash piling costs are related to total basal area removals (including commercial harvesting).

To determine the specified costs, these models are evaluated with respect to the appropriate input data prescribed by the change in management.

Conclusions.--The direct cost (in current dollars) for precommercial thinning and slash piling with only a sawtimber market is $70.15 per acre, or $175,375 in total. Corresponding cost with both sawtimber and pulpwood markets is nearly $61.30 per acre, or $153,250 in total.

Suitability Determination

As previously mentioned, a multifunctional inventory must provide a basis from which a variety of questions that land management specialists may ask regarding the feasibility of imposing a management practice can be answered. One approach to this end involves the application of forest stocking equations (Ffolliott and Worley 1973). Stocking equations relate proportions of a forest stocked (the dependent variable, in percent) to minimum basal area levels (the independent variable, in square feet per acre) dictated by management objectives.

The synthesis of stocking equations, using point sampling techniques, is based on two assumptions: (1) a sample point is stocked to a given minimum basal area level if at least one tree is tallied with a BAF corresponding to that level, or not stocked at that level if no trees are tallied; and (2) the proportion of a forest stocked to a given basal area level can be estimated from the proportion of sample points stocked to that minimum level, assuming the sampling of stocking conditions is unbiased (Ffolliott and Worley 1973). Therefore, relationships can be defined between proportions of a forest stocked to minimum basal area levels corresponding to an array of basal area factors used in an inventory, and the equations describing these relationships are stocking equations.

It will be assumed in this paper that stocking equations previously developed for cutover southwestern ponderosa pine forests (Ffolliott and Worley 1973) are appropriate for the 2,500-acre tract in this hypothetical example.

The proposed management practice that has been prescribed for the 2,500-acre tract is aimed at reducing the present overstory density level of 150 square feet of basal area per acre to 75 square feet. For illustrative purposes, it can be assumed that the 75 square foot level is the "optimum" in terms of sawtimber production. However, a stocking equation for sawtimber may reveal (as it does in this example) that only 33 percent of the tract could meet the treatment objective. A decision may now be required to assess treatment feasibility. Perhaps, the original prescription could be discarded in favor of one that would place a larger proportion of the tract under treatment, such as thinning to 35 square feet. Thinning to this alternative basal area level may result in lower sawtimber production. But, due to a greater proportion of the tract being treated, the outcome may be more favorable in the long run. The final decision must be a compromise between obtaining the "optimum" sawtimber production and extending the treatment to the largest possible proportion of the tract.

Similar analytic developments can be made to ascertain the suitability of the proposed management practice with respect to impacts on other natural resource products and uses.

CONCLUSIONS

By careful selection of pertinent research findings, a multifunctional inventory can be designed for multiple use evaluation. In essence, such an inventory provides a basis for choosing the best land management practice from a number of alternatives by estimating (primarily through indirect measurement) present and future natural resource products and uses, direct benefits and costs, and suitability of a tract of land for the proposed management alternatives.

The information resulting from the inventory may be useful to small landowners in deciding the best management for their forest. Alternative management options can be tested to help decide what might be expected to lose or gain.

The resultant information array may also be used for multiple use coordination on large tracts of land administered along company or agency lines. Such information forms a basis for selecting a management alternative (or group of alternatives), and for deciding on the best course of action for the selected alternative.

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Reconnaissance Biophysical Soil Inventories in British Columbia: A Case Study of the Northeast Coal Area[1]

Terje Vold[2]

Abstract.--The biophysical soil classification scheme used in the Northeast Coal Area allows for rapid inventory of large and remote tracts of land. The inventory permits regional evaluation of biophysical resource capabilities for various land uses as well as general assessment of particular development proposals.

INTRODUCTION

Biophysical soil inventories in British Columbia differ from traditional soil inventories insofar as soils are differentiated by integrating both biological and physical components of land. Biophysical inventories are conducted by the province's Resource Analysis Branch; most inventories are reconnaissance and cover large geographic areas, for instance the Northeast Coal Study Area (fig. 1). The biophysical soils inventory for the Northeast Coal Area is described in this paper.

This inventory is part of a larger environmental program conducted by the Resource Analysis Branch which also includes inventories of climate, surficial geology, vegetation, aquatics, wildlife, recreation, and visual resources (E.L.U.S.C. 1977). Walmsley (1976) provides a brief description of the entire biophysical system used by the Resource Analysis Branch, which is explained in more detail in workshop proceedings entitled *Natural Resource Inventory* (1976).

The main objectives of the biophysical soil inventory for the Northeast Coal Study Area are threefold:

(i) to describe and map biophysical soil resources at scales of 1:50,000 and 1:250,000;
(ii) to interpret the various soils with respect to their relative suitability for various land uses including forestry, agriculture, wildlife, recreation, visual and engineering; and
(iii) to provide basic data for environmental impact assessment of development proposals in the study area, including various railway, highway, pipeline, and townsite locations.

GENERAL DESCRIPTION OF AREA

Study Location

The study area is located (fig. 1) northeast of Prince George and southwest of Dawson Creek, between 54°30' and 55°45' North latitude, and 120°00' and 122°30' West longitude. The size of the study area is approximately 4,500 square miles or three million acres. The area is remote with only a few unpaved resource roads.

Physiographic Regions and Bedrock Geology

The study area has been divided into four major physiographic regions according to Holland (1964): The Alberta Plateau, The Rocky Mountain Foothills, the Rocky Mountains, and the Rocky Mountain Trench.

The Alberta Plateau (fig. 2) is characterized by rolling upland topography underlain by carbonaceous sandstone and shales with minor conglomerates. Elevation ranges from 1,800 to 4,500 feet above sea level. The region occurs in northeastern and eastern portions of the study area.

The Rocky Mountain Foothills (fig. 3) is characterized by a series of subparallel ridges and valleys underlain by folded and faulted

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Figure 1.--Location of Northeast Coal Study Area

Figure 2.--Alberta Plateau

sandstone and shales which have a general elevation range of between 2,000 to 6,000 feet. The Foothills occupy central and northwestern portions of the study area and include most of the proposed coal developments.

The Rocky Mountains region (fig. 4) is characterized by a series of subparallel ridges and valleys underlain by complex faulted and folded sequences of limestone, dolomite, quartzite, conglomerate, schist, sandstone, and shale. Elevation ranges from 2,500 to 7,200 feet above sea level. The Rockies occupy central and southwestern portions of the study area.

Figure 3.--Rocky Mountain Foothills. Coal exploration activities occur in this region.

Figure 4.--Rocky Mountains

The Rocky Mountain Trench is a structurally-controlled erosional feature which, like the Foothills and Rockies, trends northwest to southeast. The region varies from 2,400 to 3,000 feet elevation. The Trench occupies the extreme southwestern portion of the study area.

Surficial Materials (Soil Parent Materials)

Six major types of surficial materials were identified in the study area: morainal, colluvial, organic, lacustrine, active fluvial (floodplain), and inactive fluvial (including glaciofluvial). Surficial materials are further differentiated by texture, surface expression, and modifying processes according to methods described by the B.C. Resource Analysis Branch's (1976) *Terrain Classification System.*

The delineation of surficial materials is essential to the biophysical soil inventory and to interpretations for land use. For example, lacustrine deposits, which are dominantly fine-textured and stone-free, are the most favorable materials for agricultural use when climate is not restricting; they are also highly susceptible to piping and erosion, with silt and clay particles causing high sedimentation potential. Thus, lacustrine materials require careful management. Inactive fluvial and glaciofluvial materials are important in that they are primary sources of aggregate (sand and gravel), and they are generally the most suitable materials for intensive developments (i.e. dwellings, roads, campgrounds).

Vegetation

Due to the influences of regional climate and local climate differences resulting from elevational changes, four major vegetation zones were recognized in the study area. These zones reflect macro-climatic conditions and are based on climatic climax vegetation. Vegetation zonation concepts used by the Resource Analysis Branch are explained by van Barneveld (1976) and are similar to Daubenmire (1968) and Krajina (1969).

The four vegetation zones recognized are: the Boreal white spruce (*Picea glauca*) zone; the Subboreal white spruce-alpine fir (*Picea glauca-Abies lasiocarpa*) zone; the Subalpine Engelmann spruce-alpine fir (*Picea engelmannii-Abies lasiocarpa*) zone; and the Alpine tundra zone.

The Boreal zone extends up to 4,000 feet in the Alberta Plateau and to 3,600 feet in the Foothills. Climatic climax stands are characterized by white spruce. Most areas, however, are in various seral stages, chiefly due to fire history. Trembling aspen (*Populus tremuloides*), balsam popular (*Populus balsamifera*), and lodgepole pine (*Pinus contorta latifolia*) are common seral tree species. Black spruce (*Picea mariana*) forms edaphic climaxes with tamarack (*Larix laricina*) on poorly drained soils.

The Subboreal zone extends up to 3,800 feet in the Rocky Mountains and Foothills. Climatic conditions within the Subboreal zone are milder than the Boreal zone, with warmer temperatures and greater precipitation. Climax stands are characterized by white spruce and alpine fir. Lodgepole pine and western white birch (*Betula papyrifera commutata*) are two common trees comprising seral stands in this zone. Black spruce and, occasionally, lodgepole pine form edaphic climaxes on poorly drained soils.

The Subalpine zone occurs in the higher elevation of the Rocky Mountains and Foothills, usually between 3,500 to a maximum of 6,000 feet elevation. This zone experiences cooler year-round temperatures and deeper snow conditions than the previous zones. Climax stands are characterized by Engelmann spruce and alpine fir with an understory shrub layer characterized by mountain rhododendron (*Rhododendron albiflorum*). The zone is subdivided into forested and krummholz subzones, based on tree physiognomy.

The Alpine tundra zone occurs in the very high elevations of the Rocky Mountains and Foothills, usually above 5,800 feet elevation. Climatic conditions are so severe that trees are unable to establish themselves and periglacial (cold climate) processes such as cryoturbation (frost churning), solifluction, and nivation are frequently active. Common plants include white heather (*Cassiope spp.*), red heather (*Phyllodoce spp.*), mountain-avens (*Dryas spp.*), crowberry (*Empetrum nigrum*), willows (*Salix spp.*), and lichens.

Soil Development

Six soil orders occur in the study area; these are Luvisolic[3] (Boralfs[4]), Brunisolic (Inceptisol), Podzolic (Spodosol), Regosolic (Entisol), Gleysolic (Aqu-suborders), and Organic (Histosol) orders.

Luvisolic soils are characterized by a horizon of clay accumulation which tends to inhibit both water movement and root penetration in the soil; Gray Luvisol is the main great group in the study area. This development is dominant in the Alberta Plateau, Rocky Mountain Foothills, and Rocky Mountain Trench on morainal and lacustrine parent materials.

Brunisolic soils have weakly expressed soil horizons and dominantly occur in high elevations on the east side of the continental divide where long winters, low temperatures, and relatively low precipitation restrict soil weathering.

Podzolic soils are characterized by accumulations of iron, aluminum, and organic matter in subsurface horizons through leaching and occur in areas of high precipitation, which are dominantly on the west side of the continental divide. Humo-Ferric Podzol is the dominant great group in the study area.

Regosolic soils are very weakly developed and lack a B horizon. They are restricted to areas that are periodically disturbed, either

[3]The System of Soil Classification for Canada. Canada Dept. Agric. (1974).
[4]Soil Taxonomy. U.S. Soil Survey Staff (1975).

due to flooding, severe mass wasting, or frost heaving (cryoturbation). Thus, Regosolic soils are restricted to floodplains, steep colluvial deposits, and deposits in the Alpine tundra zone.

Gleysolic soils are saturated with water and are under reducing conditions for most of the year. These soils are poorly drained and occur on depressional to level topography or on gentle to moderate slopes receiving seepage; they dominantly occur in the Alberta Plateau.

Organic soils are composed mainly of organic matter and have developed under saturated conditions. They occur in localized areas throughout the study area.

SURVEY PROCEDURES

Prior to fieldwork, landforms were pretyped on aerial photographs at approximate scale of 1" = 1 mile using the B.C. Resource Analysis Branch's (1976) system of terrain classification. Vegetation zonation maps and descriptions were provided during the field season by a separate vegetation crew.

Field survey by truck on existing roads and by helicopter in relatively inaccessible areas provided field checking of air-photo interpretation. Soils were examined at each stop and field descriptions were recorded on such internal soil properties as horizonation, depth, colour, texture, pH, and drainage. Terrain features such as slope, elevation, rockiness, aspect, and vegetation were also noted on field cards. Soil development was taxonomically described at the subgroup level using The System of Soil Classification for Canada (Canada Dept. Agric. 1974).

Following field examination in several locations, a biophysical soils legend for the study area was developed. Representative soils in the study area were sampled and morphologically described in detail and analyzed with respect to their physical and chemical characteristics. Field checking resulted in modification of pre-typing, with final lines being plotted on aerial photographs. These boundaries were then transferred to 1:50,000 scale topographic base maps for compilation.

BIOPHYSICAL CLASSIFICATION METHODOLOGY

Biophysical soil resources were differentiated by integrating both physical and biological components of land and by using a hierarchical scheme (fig. 5) which allows for regional and local representation of land resources.

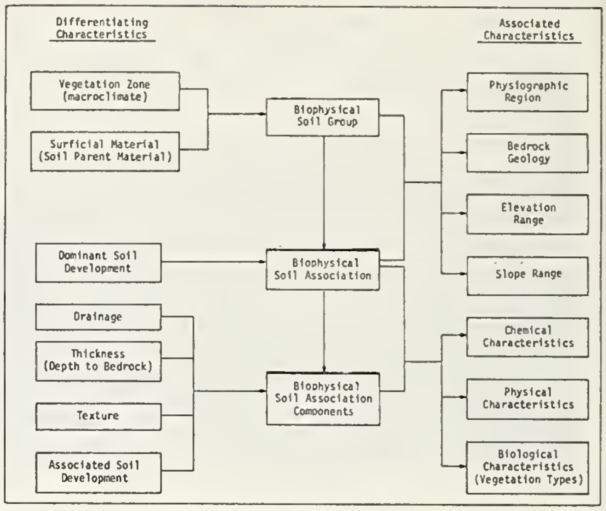

Figure 5.--Biophysical Classification Scheme

Biophysical soil groups represent the most general level of classification and were mapped at a scale of 1:250,000. A biophysical group is defined as a similar soil parent material or surficial material occurring under similar climatic conditions as expressed by vegetation zone. Significant edaphic differences such as poor drainage modified this definition. Associated characteristics such as physiographic region and bedrock geology are strongly correlated with biophysical groups. An example of a biophysical group (fig. 6) would be medium-textured morainal materials in the Boreal white spruce zone, which dominantly occurs in the Alberta Plateau and overlies sandstone and shale bedrock. Biophysical soil groups were introduced in the study area in order to provide a regional perspective of land resources that have similar interpretive characteristics for land use.

Biophysical soil associations represent the next level of classification and were used as an initial mapping device on 1:50,000 scale maps. A biophysical soil association is defined as similar parent materials, occurring under similar climatic conditions as expressed by vegetation zone, and having similar modal soil development. Essentially, associations are biophysical groups which are differentiated by differences in modal soil development. For example, a biophysical group consisting of fine-textured morainal materials in the Boreal white spruce zone was separated into two associations: one with Orthic Gray Luvisol and another with Brunisolic Gray Luvisol soil development. A soil association, however, has different characteristics due to variation in relief, drainage, and thickness. Soil associations are used for most of British Columbia's land inventories (i.e. Runka 1972).

Table 1.--Generalized Biophysical Soil Association Legend

VEGETATION ZONE	PHYSIOGRAPHIC REGIONS	SURFICIAL MATERIAL (Soil Parent Material)		MODAL SOIL DEVELOPMENT	BIOPHYSICAL SOIL ASSOCIATIONS Name	Symbol	BIOPHYSICAL SOIL GROUPINGS
BOREAL	Alberta Plateau to Rocky Mountain Foothills	Morainal	fine-textured	Orthic Gray Luvisol	Edson	ED	1
				Brunisolic Gray Luvisol	Fellers	FE	
			medium-textured	Brunisolic Gray Luvisol	Moberly	MO	2
			medium-textured with sandy capping	Brunisolic Gray Luvisol	Lodge	LG	
			variable-texture, poorly-drained	Orthic Gleysol	Smoky	SY	3
		Lacustrine	fine-textured	Dark Gray Luvisol Brunisolic Gray Luvisol Orthic Gray Luvisol	Devereau Dickebusch Tri Creek	DU DB TC	4
			fine-textured, poorly-drained	Orthic Luvic Gleysol	Snipe	SN	3
		Colluvial	variable-texture	Orthic Regosol Degraded Dystric Brunisol Degraded Eutric Brunisol	Septimus Squaw Mountain Zonnebecke	SS SQ ZB	5
		Floodplain	calcareous	Cumulic Regosol	Detca	DE	
			non-calcareous	Cumulic Regosol	Meikle Creek	ME	6
			non-calcareous fans	Cumulic Regosol	Windfall Creek	WF	
		(Glacio-) Fluvial	gravelly	Brunisolic Gray Luvisol Degraded Eutric Brunisol Degraded Dystric Brunisol	Jarvis Portage Creek Neumann	JR PT NE	7
			sandy	Brunisolic Gray Luvisol	Sundance	SU	
			poorly-drained	Orthic Gleysol	Gunderson	GN	3
		Organic	bog	Mesisol	Kenzie	KZ	8
			fen	Mesisol	Eaglesham	EG	
SUBBOREAL	Rocky Mountain Foothills to Rocky Mountains	Morainal	fine-textured, shallow till over weathered siltstone	Brunisolic Gray Luvisol	Imperial Creek	IC	9
			medium-textured	Brunisolic Gray Luvisol Degraded Eutric Brunisol Degraded Dystric Brunisol	Bulley Crum Mountain Lean-to	BL CM LT	
		Lacustrine	fine-textured	Brunisolic Gray Luvisol	Dokken	DK	10
		Colluvial	medium-to-coarse textured	Degraded Dystric Brunisol Degrade Eutric Brunisol	Spieker Mountain Suprenant Mountain	SP ST	11
		Floodplain	calcareous	Cumulic Regosol	Monkman Creek	MK	12
			non-calcareous	Cumulic Regosol	Bullmoose	BM	
		(Glacio-) Fluvial	sandy or gravelly	Orthic Humo-Ferric Podzol Degraded Eutric Brunisol	Triad Creek Kinuseo	TO KO	13
	Rocky Mountains to Rocky Mountain Trench		moderate-textured	Orthic Humo-Ferric Podzol	Abbl Mountain	AB	
			gravelly with deep sandy capping	Orthic Humo-Ferric Podzol	Toneko	TO	
			gravelly	Orthic Humo-Ferric Podzol	Ramsey	RM	
		Morainal	medium-textured	Podzolic Gray Luvisol	Dominion	DO	14
		Lacustrine	fine-textured	Podzolic Gray Luvisol	Bednesti	BD	15
		Colluvial	medium-textured	Orthic Ferric-Humic Podzol	Barton	BT	16
		Floodplain	sandy	Cumulic Regosol	Mokus Creek	MU	17
			silty	Gleyed Orthic Regosol	McGregor	MG	
	Foothills to Trench	Organics	bog	Mesisol	Mitska	MT	8
			fen	Mesisol	Whatley	WH	
			bog	Fibrisol	Moxley	MX	
			fen	Fibrisol	Chief	CF	
SUBALPINE, FORESTED SUBZONE	Rocky Mountain Foothills to Rocky Mountains	Morainal	fine-textured	Brunisolic Gray Luvisol	Hambrook	HB	18
			sand capping	Brunisolic Gray Luvisol	Footprint	FT	
			medium-textured	Brunisolic Gray Luvisol	Onion Creek	ON	
			shallow, coarse-textured	Brunisolic Gray Luvisol	Thunder Mountain	TH	
			coarse-textured	Degraded Eutric Brunisol Orthic Humo-Ferric Podzol	Robb Turning Mountain	RB TM	
			medium-textured	Orthic Humo-Ferric Podzol	Beauregard Mountain	BG	

Table 1 (Continued)

VEGETATION ZONE	PHYSIOGRAPHIC REGIONS	SURFICIAL MATERIAL (Soil Parent Material)		MODAL SOIL DEVELOPMENT	BIOPHYSICAL SOIL ASSOCIATIONS Name	Symbol	BIOPHYSICAL SOIL GROUPINGS
		Lacustrine	fine-textured	Orthic Humo-Ferric Podzol	Dudzic	DC	19
		Colluvial	derived from limestone and dolomite	Degraded Eutric Brunisol Orthic Melanic-Brunisol Orthic Humo-Ferric Podzol	Wendt Mountain Myhon Hedrick	WT MH HK	
			derived from conglomerate	Degraded Dystric Brunisol	Quintette	QT	20
			derived from sandstone and shale	Orthic Humo-Ferric Podzol Degraded Dystric Brunisol	Merrick Horseshoe	MC	
			derived from siltstone	Brunisolic Gray Luvisol	Blue Lake	BE	
			derived from metamorphic bedrock	Orthic Humo-Ferric Podzol	Dezaiko	DZ	
		Floodplain	coarse-textured	Cumulic Regosol	Knudsen Creek	KN	21
		Organic	bog	Fibrisol	Hominka	HA	8
		(Glacio-) Fluvial	coarse-textured	Brunisolic Gray Luvisol Degraded Dystric Brunisol Orthic Humo-Ferric Podzol	Five Cabin Creek Holtslander Ovington Creek	FC HD OV	22
KRUMMHOLZ SUBZONE		Morainal	coarse-textured	Orthic Humo-Ferric Podzol	Paxton Mountain	PX	
		Colluvial	derived from sandstone and shale	Orthic Sombric Brunisol	Reesor	RR	
			derived from limestone and dolomite	Lithic Orthic Melanic Brunisol	Sheba Mountain	SB	23
			derived from metamorphic bedrock	Orthic Humo-Ferric Podzol	Misinchinka	MS	
ALPINE	Rocky Mountain Foothills to Rocky Mountains	Colluvial	derived from sandstone and shale	Turbic Orthic Regosol	Palsson	PL	
			derived from limestone and dolomite	Lithic Orthic Regosol	Tsahunga	TS	24
			derived from metamorphic bedrock	Lithic Orthic Regosol	Gable Mountain	GM	
SUBALPINE AND ALPINE	Rocky Mountains	Colluvial (talus)	rubbly, derived from limestone and dolomite	Orthic Regosol	Becker Mountain	BC	25
			rubbly, derived from metamorphic	Orthic Regosol	Tlooki	OO	

Figure 6.--Biophysical Soil Group 2--medium-textured morainal materials in Boreal white spruce zone.

Biophysical soil association components are the basic mapping units for 1:50,000 scale maps. Components of an association are separated on the basis of drainage, depth to bedrock, texture, or associated soil development. For example, the above described associations can be separated into components that are imperfectly versus well-drained, and deep versus shallow over bedrock.

Biophysical land inventories in British Columbia are similar in concept to the "land systems" approach described by Lacate (1969) and used throughout most of Canada (Jurdant et al. 1975). For instance, biophysical soil associations are similar to land systems, and components are similar to land types.

RESULTS

Twenty-five biophysical soil groups, 75 biophysical soil associations, and nearly 300 soil association components were recognized in the study area. Table 1 represents a generalized legend for biophysical soil associations and groups. Table 2 has been extracted from a detailed legend for soil association components and illustrates how components are differentiated.

Table 2.--Portion of Legend for Biophysical Soil Association Components of the Boreal white spruce zone

SURFICIAL MATERIAL	SOIL ASSOCIATION	SOIL[1] ASSO. COMP. SYMBOL	MODAL[2] SOIL DEV'L	ASSO.[2] SOIL DEV'L	TERRAIN[3] SYMBOL	CDA[4] TEXTURE (<2mm)	(%)[5] COARSE FRAG-MENTS (by vol.)	DRAIN-[6] AGE CLASS	DEPTH TO BEDROCK (cm)	COMMON[7] SLOPE RANGE (%)	COMMON ELEVATION RANGE (feet)	PHYSIO-[8] GRAPHIC REGION(S)	REMARKS
Morainal	Edson	ED1	O.GL		Mbm	cl or c	0-5	MWD	>100	2-30	2000-2500	Plains	Continental till; calcareous <100cm. Commonly under cultivation.
		ED3	O.GL	BR.GL	Mbm	cl or c	0-5	MWD	>100	2-30	2000-2500		
		ED5	O.GL	L.O.GL	Mbv	cl or c	0-5	MWD	10-100+	9-30	2000-2500		
		ED7	O.GL	GL.O.GL	Mbm	cl or c	0-5	MWD-ID	>100	2-15	2000-2500		
		ED8	O.GL	.G	Mbm	cl or c	0-5	MWD-PD	>100	2-15	2000-2500		
	Fellers	FE1	BR.GL		Mb	sicl-cl	0-10	MWD	>100	2-30	2400-3700	Benchlands	Cordilleran till; calcareous >100cm. Seral aspen stands common.
		FE4	BR.GL	GL.O.GL O.GL	Mbv	cl or c	0-5	MWD-ID	>50	2-9	2400-3700		
		FE7	BR.GL	GL.BR.GL	Mb	sicl-cl	0-10	MWD-ID	>100	2-15	2400-3700		
	Lodge	LG1	BR.GL		Fv/Mbm	sl/c-l	0/0-30	MWD-WD	>100	2-30	2000-4000	Plains,	Continental or cordilleran till; 15-50cm sandy loam fluvial capping. Seral aspen stands common.
		LG2	BR.GL	O.GL DG.EB	Fv/Mbm	sl/c-l	0/0-30	MWD-WD	>100	2-30	2000-4000	Benchlands,	
		LG3	BR.GL	P.GL	Fv/Mbm	sl/c-l	0/0-30	MWD-WD	>100	2-30	3000-4000	Foothills	
		LG4	BR.GL		Fv/Mbm	sl/c-l	20-50/0-30	WD	>100	2-30	3000-3500		
		LG7	BR.GL	GL.BR.GL	Fv/Mbm	sl/c-l	0/0-30	MWD-ID	>100	2-30	2000-4000		
		LG8	BR.GL	.G	Fv/Mbm	sl/c-l	0/0-30	MWD-PD	>100	2-30	2000-4000		
	Moberly	MO1	BR.GL		Mb	cl-l	5-30	WD-MWD	>100	2-30	2000-4000	Benchlands,	Cordilleran till; calcareous <100cm. Seral aspen stands common; early aeral willow shrubs and climax spruce stands also occur.
		MO2	BR.GL	DG.EB	Mb	cl-l	5-30	WD-MWD	>100	2-30	2000-2500	Foothills	
		MO3	BR.GL	P.GL	Mb	cl-l	5-30	WD-MWD	>100	2-30	3000-4000		
		MO4	BR.GL	DG.EB O.EB	Mb	sl-cl	5-30	WD-MWD	>100	2-30	2000-4000		
		MO5	BR.GL	L.BR.GL	Mbv	cl-l	5-30	WD-MWD	10-100+	2-30	2000-4000		
		MO6	L.BR.GL	BR.GL	Mv	cl-l	5-30	WD-MWD	10-100	2-30	2000-4000		

INTERPRETATIONS FOR LAND USE

Generalized interpretations for forestry, agriculture, wildlife, recreation carrying capacity, visual absorption capability, and engineering are indicated on table 3 for each biophysical soil group. Since biophysical groups have broadly similar interpretive characteristics for land use, they are useful in that they provide a regional understanding of the extent and distribution of resource values in the study area. This overview perspective is considered essential for regional resource planning.

More detailed interpretations for each biophysical soil association component and methods of analysis are provided in the report for the study area (Vold, in preparation); these interpretations are intended for resource managers.

Agriculture

Agriculture capability ratings are provided in table 3 using methods developed by the Canada Land Inventory[5] (1965b) and

[5]For a general discussion of the Canada Land Inventory (C.L.I.) Program, refer to C.L.I. (1965a).

Table 3.-- BIOPHYSICAL GROUPS AND GENERALIZED LAND USE INTERPRETATIONS

Biophysical Groups	Vegetation Zone	Parent Materials (Surficial ")	Capability Ratings for: Agriculture	Forestry	Ungulates	Recreation Carrying Capac.	Visual Absorption Capability	Engineering Suitability
1	Boreal	Morainal,fine-text.	L-M	M	M-H	M	M	L-M
2	Boreal	Morainal,med.-text.	L	M	M-H	M	H	M-L
3	Boreal	Variable,poorly drained	L	L	M-H	L	M	L
4	Boreal	Lacustrine	M-H	L	H	M	M	L-M
5	Boreal	Colluvial	L-N	L	M-H	L	M-L	L
6	Boreal	Fluvial,active	M-L	H	H	L	H	L
7	Boreal	Fluvial,inactive	L	M	L-M	H	H	H
8	All Zones	Organic	L-N	L-N	L-M	L	M	L
9	Subboreal	Morainal[1]	L	M	L-M	M	H	M-L
10	Subboreal	Lacustrine[1]	M-L	L	L-M	M	M	L-M
11	Subboreal	Colluvial[1]	L-N	L	L	L	M-L	L
12	Subboreal	Fluvial,active[1]	L-M	M	M-H	L	H	L
13	Subboreal	Fluvial,inactive	L	M	L	H	H	H
14	Subboreal	Morainal [2]	L	H	L-M	H-M	H	M-L
15	Subboreal	Lacustrine[2]	M-L	H	L-M	M	M	L-M
16	Subboreal	Colluvial[2]	L-N	M	L	L	L	L
17	Subboreal	Fluvial,active[2]	L-M	H	M-H	L	H	L
18	Subalpine	Morainal	N	L	L-M	M-H	M	L-M
19	Subalpine	Lacustrine	N	L	L-M	M	L	L-M
20	Subalpine	Colluvial	N	L	L-M	L	L	L
21	Subalpine	Fluvial,active	N	L	L-M	L	M	L
22	Subalpine	Fluvial,inactive	N	L	L-M	H	M	H
23	Subalpine, krummholz	Colluvial	N	N	L-M	L	L	L
24	Alpine	Colluvial	N	N	L-M	L	L	L
25	Alpine & Subalpine	Coluvial(talus)	N	N	L	L	L	L

1/ Foothills to Rockies, east side Divide
2/ Trench to Rockies, west side Divide

H = High M = Moderate L = Low N = Nil

Runka (1973). These ratings are based on the range of crops possible and not on productivity of any crop. The four generalized capability classes recognized are high, moderate, low and nil.

Forestry

Forest capability ratings are provided in table 3 using methods developed by The Canada Land Inventory (1967) and Kowall (1971) which assess forest productivity. Four generalized capability classes were used for biophysical soil groups: high (greater than 90 cubic feet/acre/year); moderate (51-90); low (11-50); and nil (less than 11). Seven classes were used for biophysical soil association components with limitations also expressed.

In the biophysical soils report (Vold, in preparation), interpretations are also provided for tree species suitability for regeneration, limitations for regeneration, windthrow hazard, limitations for logging roads, and erosion hazard.

Wildlife

Biophysical capability ratings for wildlife (ungulates) are provided in table 3 using methods developed by The Canada Land Inventory (1969) and modified by Blower (1973), Luckhurst et al. (1973), and Luckhurst (1975). Generalized classes of high moderate and low are used to indicate ungulate capability for each biophysical soil group.

In the report, capability ratings are provided for each ungulate species (moose, elk, whitetailed deer, mule deer, mountain goats, and caribou) and upland game birds. General forage quantity ratings are also provided.

Recreation

Recreation carrying capacity ratings are provided in table 3 using methods developed by Block and Hignett (1976). Three generalized classes were recognized: high physical carrying capacity suitable for intensive recreational use; moderate carrying capacity suitable for extensive, but not intensive recreational use; and low carrying capacity which has severe limitations affecting both intensive and extensive recreation.

Visual

Generalized interpretations for the visual absorption capability of biophysical groups are provided in table 3 using methods discussed by Anderson et al. (1976) and Litton (1974). These ratings indicate land's intrinsic ability to absorb modification and meet visual quality objectives by assessing slope, erosion hazard potential, revegetation potential, and vegetation diversity. A three class system is used with high, moderate, or low visual absorption capabilities indicated.

Engineering

Generalized interpretations for engineering are provided in table 3 which indicate the relative performance of biophysical groups for most engineering uses of land.

In the report, specific interpretations are provided for septic tank absorption fields, shallow excavations, dwellings, local roads, road fill, aggregate source, topsoil, and frost action potential. U.S.D.A. Soil Conservation Service (1971) guidelines are used to develop these interpretations.

DISCUSSION

The generalized land use interpretations in table 3, which are based on the biophysical soil inventory for the Northeast Coal Study Area, allow for some degree of comparison of several regional resources. For a more complete comparison, the other environmental inventories conducted in the study area should also be assessed. For example, recreation and visual features, and aquatic resources need to be assessed. Also, comparison of regional resource values requires socio-economic analysis. Nevertheless, biophysical soil resource inventories and their interpretation for various land uses are an important component of regional resource planning.

As mentioned, more detailed interpretations are available for biophysical soil association components which permit more specific assessment of resources. These interpretations were also used to assess the impacts of coal development proposals including various railway, highway, pipelines, and townsite locations. Some route options were preferred on the basis of fewer soil limitations which reduce construction costs, and fewer soil hazards which reduce environmental costs (i.e. less erodable soils with lower siltation hazard).

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Integrated Inventories in the Tennessee Valley Region[1]

Robert P. Gregory[2]

Abstract.--The Tennessee Valley Authority currently uses several methodologies for integrated inventory and analysis of terrestrial and aquatic natural resources. Four of particular interest to forest resource specialists are the Woodland Resource Analysis Program (WRAP), the environmental assessment survey, the land analysis system, and the forest and wildland resources inventory. This last method is the one in longest application. It has been used to assess small forest properties as well as forests of the entire region. The method is basically a continuous forest inventory that has been amplified by a number of supplemental surveys.

INTRODUCTION

Since 1933, the Tennessee Valley Authority (TVA) has had the job of helping develop the resource potential of the 36.6 million acre (14.8 million ha) Tennessee River Valley. All Valley resources are considered--land, air, water, soil, forests, minerals, fish, wildlife, and people. As a result, information about these resources is being collected for synoptic analysis and for site-specific needs, often in cooperation with other agencies.

Over the years, TVA has used a number of survey techniques to gather resource data. Today, TVA is continuing to test and demonstrate methods for improving the integration of collecting and analyzing data and of presenting the resulting information.

The objectives of this paper are: (1) to describe TVA, what it is, what it does, how it is organized, and how information is used; (2) to share experiences in inventory and analysis of renewable natural resources; (3) to help others gain insight from these experiences; and (4) to appraise the future direction of such data acquisition, analysis, and use.

The balance of the paper is divided into three parts. The first part provides the basis for understanding TVA. The second describes the Division of Forestry, Fisheries, and Wildlife Development and briefly reviews some of the more important survey methods used. Also discussed are several ways the integration of information is achieved. The final section is devoted to the forest and wildland resources inventory, a classic example of a multiresource survey, in use since 1962. It is now undergoing a thorough reassessment of its relevancy to current information needs.

BACKGROUND

Profile of the Tennessee Valley

The Tennessee River Valley is an area of 36.6 million acres (14.8 million ha). It consists of the 125 counties that drain into the Tennessee River or its tributaries (fig. 1). These counties lie within the seven states of Alabama, Georgia, Kentucky, Mississippi, North Carolina, Tennessee, and Virginia. The Tennessee River Watershed is the fourth largest river system in the nation.

Forests are the major land cover. Approximately three-fifths of the Valley is forest land supporting a forest industry which ranks fourth in employment and wages among Valley manufacturing industries. Of these 21.6 million acres (8.7 million ha), over 70 percent are privately owned.

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[1]Paper presented at the Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 9-12, 1978.

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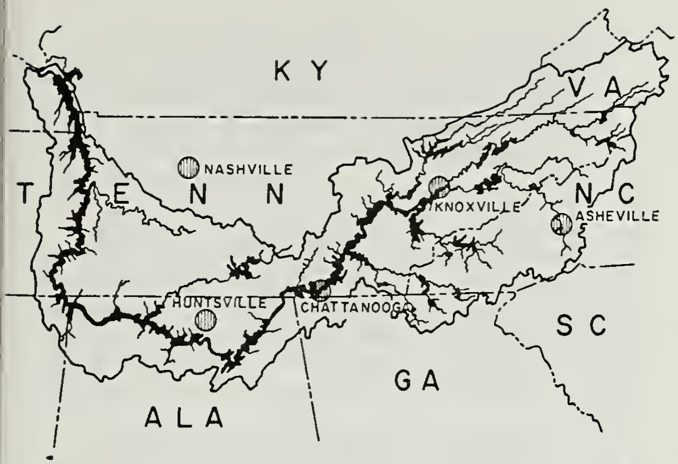

Figure 1.--The Tennessee Valley Region.

The Tennessee Valley Authority

The Tennessee River Valley in 1930 was badly depleted. Per capita income was less than half the national average. Erosion was widespread. Fires annually destroyed 10 percent of the forests and prevented the revegetation of deforested land. Surviving forests were poor in quality and stocking. Timber harvests exceeded growth.

There were other problems. The rivers of the Tennessee Valley frequently flooded in the winter and spring but were shallow uncertain channels in the summer and fall. Industrial development lagged, employment opportunities were scarce, and outward migration was common. Electrification did not extend to rural areas.

To help resolve this complex of interrelated problems, the Tennessee Valley Authority was created by Congress in May 1933. TVA is a corporate agency of the Federal government and enjoys a reasonable degree of autonomy and flexibility. Its program is determined by a three-member Board of Directors.

TVA has been given the mission of accelerating the recovery and developing the potential of the Tennessee Valley. From the start, TVA has sought to improve the quality of life for Valley residents. A unified program calls for the proper development, use, and conservation of all natural resources. TVA's role is to explore, test, and demonstrate the best methods of developing and utilizing the Valley's resources in cooperation with public agencies, organizations, and citizens.

TVA is not a land management agency. Less than 3 percent of the Valley is owned by TVA. A third of that is devoted to uses such as steam plant sites and dam reservations. Approximately 683,000 acres (227,000 ha) are identified as forest or wildland and therefore eligible for multiple use management. However, except for some experimental areas, no TVA lands are retained specifically for forest production. Rather, lands are retained because of their contribution to program needs, for example, recreation.

The ability of TVA to acquire adequate information upon which to base decisions is the keystone of the entire resource development program. From the outset, the framers of the TVA Act recognized the importance of adequate information. TVA is authorized to make any necessary surveys within the basin and adjoining territory. Demonstration of innovative survey techniques and methods is even encouraged.

Information, of and by itself, is fully as important a product of TVA as is river control or electrical energy. Information produced by TVA is used to guide decision making, both inside and outside the agency. TVA early recognized the importance of maps as both an indispensible resource development tool and as an information product. Full cartographic and remote sensing services support all TVA organizations. Up-to-date, full coverage, topographic maps of the seven-and-a-half minute series are produced by TVA's mapping program for the entire Tennessee Valley in cooperation with the U.S. Geologic Survey. Also available are collections of all remote imagery of the Valley region including a LANDSAT browse file. Maps and photographs have served as the foundation for many of the inventory procedures and analysis methods used within TVA over the years. For some types of information, maps and remote imagery may be the only archival medium. The two media are also a frequent source of information for manual and computer data bases. Both maps and photographs are widely used to integrate information for analysis, display, and communication.

The importance of information to TVA is seen in the agency-wide information systems studies that are currently underway. As the demand for information continues to rise, traditional methods of collecting, processing, and sharing data are giving way to new technologies and concepts. Computers are playing an increasing role. Automated information systems are rapidly replacing the informal information processes. Data are being viewed as an agency resource. To avoid inefficiencies, information plans are being developed to assist the whole agency in satisfying short-term and long-term information needs. This is the first step in planning for integrated information systems and shared data bases. As a major data user with a mandate to innovate, TVA has a unique

opportunity to develop and demonstrate advanced methods of information delivery needed for regional development.

THE DIVISION OF FORESTRY, FISHERIES, AND WILDLIFE DEVELOPMENT

The Division of Forestry, Fisheries, and Wildlife Development (FF&WD) has the primary responsibility for guiding the development and utilization of the Valley's renewable natural resources. Headquartered at Norris, Tennessee, are fisheries biologists, foresters, environmental education specialists, land-use analysts, recreation planners, wildlife biologists, and others.

Work is divided among three branches: Fisheries and Waterfowl Resources, Recreation Resources, and Forest and Wildlife Resources. Land Between The Lakes, also part of FF&WD, is an outdoor recreation and environmental education center of 170,000 acres (69,000 ha) in western Kentucky and Tennessee, developed by TVA as a national demonstration.

Through its program, FF&WD indirectly influences the most basic natural resources which are air, water, and soil. The main thrust of its activities focuses on the renewable natural resources. These resources include plants, animals, their natural habitats, the products they produce, and the experiences they provide.

Major Approaches To Integrating Information

Any organization requires three forms of information to function efficiently. Information is needed for operations, management, and planning. The relative mix of these three information types changes at different levels of a hierarchy. The ultimate purpose of the information is to assist decision making. Information is data which have been processed and analyzed to provide insight. In FF&WD, the information model (fig. 2) is representative of the way data are gathered, stored, and analyzed into information. It shows how information is used to guide decisions, to define requirements, and to plan information systems, including inventories and surveys. The model reveals several opportunities to combine data and information to aid multi-resource development programs.

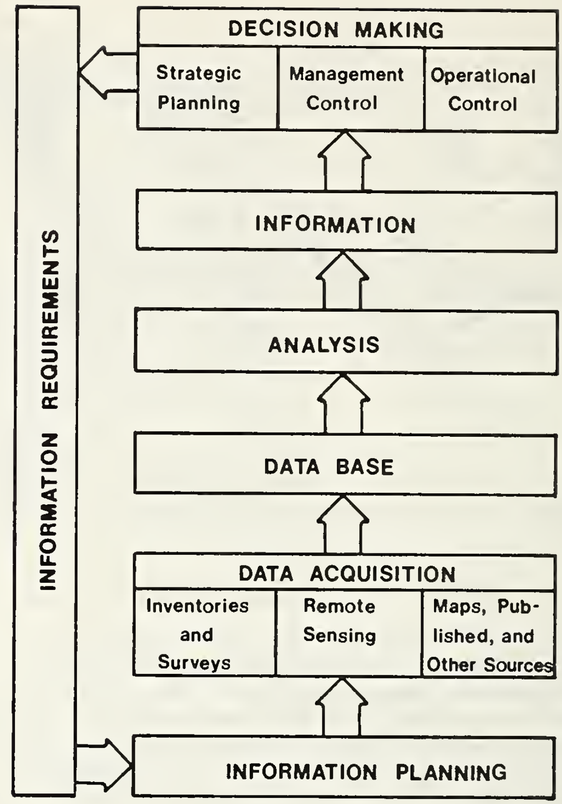

Figure 2. Natural Resources Information Model.

Today, a problem of central concern to resource analysts and managers in FF&WD is how to integrate data efficiently. Many times the information needed for strategic planning, management control, or operations is all derived from the same basic data. The difference is in the subsets of data used, the type of analysis made, the abstractions applied, the summaries produced, and the presentation formats employed. Also, at times, it is likely that data will have greater utility when combined with other information.

A highly favored approach to integrating data is through data bases. Here all logically related data are assembled in a way that permits retrieval, manipulation, analysis, and display. Data, with spatial identifications, are assembled from many sources using the most efficient methods of acquisition. Data bases increase the ability to recombine relevant data to assist in making new decisions. In addition data bases facilitate sharing of data and information between organizations.

Integrated inventories of renewable natural resources are not new to FF&WD. From

the very beginning, attempts were made to meet multiple information objectives by a single survey. A common approach which has achieved a form of integrated inventory is to conduct joint surveys with other agencies as, for example, U.S. Fish and Wildlife Service or the U.S. Forest Service.

Data to be collected in an inventory should be defined during information planning based on the information requirements. Information requirements are determined in part by decision makers, their responsibility in the organization, the types of decisions made, and the analysis needed.

Study of the requirements reveals that proper development of renewable natural resources requires a broad spectrum of information. To be comprehensive, information is needed for each resource and for each way the resource is viewed. In addition, information about the quality, quantity, and spatial location of the resource needs to be supplemented with information about the suppliers and consumers.

Fisheries and Recreation Surveys

In the Fisheries and Waterfowl Resources Branch, one objective is to improve the fishery resource base, protect its diversity of life, and manage for optimal benefits. Since fish and other aquatic life exist in a medium that makes direct observation frequently impossible, and since they are mobile within a three-dimensional space, the inventory of aquatic resources offers special survey problems. A solution is to use multiple techniques to collect the required data. In the assessment of fish populations alone, there are 17 routine types of biological and ecological study methods available. For example, in a typical power plant siting study, a crew might use gill netting, trap netting, and electrofishing techniques. Auxiliary information collected by other divisions on weather, temperature, flows, and plant operation schedules contributes to an integrated analysis of the fishery resource.

The Recreation Resources Branch carries out activities to stimulate, guide, and contribute to regional resource development, and it administers TVA's environmental education program. Basic recreation information useful to TVA, other public agencies, planning groups, and private investors is collected. One such survey estimates investment in shoreline development and recreation visits to TVA lakes.

A significant inventory recently completed is the recreation capability classification of 68 counties bordering TVA reservoirs and the Great Smoky Mountains National Park. Data on physical characteristics pertaining to recreation potential from field and published sources was recorded as distinct land units on topographic maps (TVA 1974). Each unit was examined and classified according to the types of recreation activities to which it was best suited using a modification of The Canadian Land Inventory approach (Canadian Department of Regional Economic Expansion 1970). Recreation plans for each reservoir were then produced by comparing recreation capability with demand estimates and with existing and proposed reservoir land use.

Multiresource Inventories and Analysis of Forests and Woodlands

The Forest and Wildlife Resources Branch has a broad program which ranges from tree physiology through wood as a source of energy. Work is even underway to develop wildlife habitat along TVA's transmission line rights of way and along the drawdown zones of TVA lakes. As the nation's largest single coal buyer, TVA is interested in the proper reclamation of lands disturbed by surface mining. One project is demonstrating the feasibility of reclaiming abandoned strip mines and haul roads throughout Appalachia. The magnitude of the abandoned or orphaned strip mine problem was disclosed by a multistage inventory using aerial photography and field sampling.

WRAP

With over 70 percent of the forest land of the Valley in 356,000 private ownerships, programs to improve the quality of management of these lands are emphasized. The Woodland Resource Analysis Program, known as WRAP, is a step toward total management of the forest resource. WRAP is a computer-based system with multiple resource management capability.

Information about landowner objectives is combined with information about each tract of land, its capability, and its present condition. Collection of these data requires the assistance of a trained forester as does interpretation of the results.

The result is a personalized management plan that will aid the landowner in realizing the benefits from his land. The output report contains management recommendations, potential timber harvesting schedules, and forecasts of financial benefit. Timber growth and yield

projections, wildlife productivity relationships, amenity considerations, economic analysis, and a mathematical optimization routine are all a part of WRAP. The WRAP approach of integrating specific management objectives and resource data with knowledge about ecological relationships and economic conditions should become very widespread in the Tennessee Valley as its use grows.

Environmental Assessment

The National Environmental Policy Act requires TVA, as a public agency, to assess the magnitude and nature of environmental impacts associated with its proposed activities and projects. Concern for environmental impacts is evident at the earliest stages of project planning. As project specifications and requirements are being defined, existing environmental data from TVA and other sources are reviewed. This screening process enables project planners and resource managers to determine the suitability of certain areas for planned facilities and gives early warning regarding possible conflicts.

An essential store of data for environmental assessment, land-use planning, and environmental education is available in the TVA Regional Heritage Program. Patterned after one developed by The Nature Conservancy, the data base contains over 8,000 locality records for sensitive or unique plant and animal species, historic places, archeological sites, and other features of natural or cultural significance. Information is continually added as it is acquired from published sources, museums, and from field studies of candidate facility sites. Invaluable assistance has come from researchers and scientists in the seven Valley states and beyond who have personal knowledge they are willing to share. As the site evaluation process focuses down to specific locations, more intensive studies are needed to supplement existing data and to assess directly the impacts at those points.

One important approach to integrated data gathering is the vital environmental assessment survey. This survey is keyed to the responsive and comprehensive evaluation of facility sites, transmission line corridors, and similar areas. The method is somewhat qualitative. To work well, it requires a team of recognized scientists who are familiar with the ecosystem and habitat requirements of rare and endangered species and who can recognize significant or potentially significant features. A forester, botanist, vertebrate zoologist, waterfowl biologist, recreation specialist, and possibly others thoroughly examine the area under study. For transmission line corridors, the examination is made by helicopter; any observed environmentally critical areas are then ground-checked by the appropriate scientists.

Land Analysis System

As originally conceived for use in natural resource planning, the land analysis system consists of a team-oriented decision process supported by manual and computer-assisted geographical information systems. The system incorporates several precepts. (1) Better decisions need to be made concerning the use of land,and interdisciplinary teams make better decisions. (2) Decisions must be based on simultaneous analysis of several features. (3) Geographic locations and patterns are important in analysis and in communication. (4) Maps and diagrams limited to the essential features are very efficient communicators. (5) Computer technology should be employed, but models and data bases that take years of development before producing useful products must be avoided (Howard and Baxter 1976).

The geographical information system component of the land analysis system is emerging as a versatile analytic approach with wide application. It is designed to store, manipulate, and display geographically referenced information which has been abstracted in cell or grid format. Thus it has applicabililty for almost all natural resource information. Geographical referencing of the cells by latitude and longitude permits easy registration to topographic maps (Weber and Gregory 1975). Latitude/longitude was selected as the primary referencing system because it does not have the boundary discontinuities found in plane coordinate systems. This feature is needed when dealing with large area or multistate data when the earth's curvature is a factor. Cell size varies depending on data resolution,type of analyses to be performed, decisions to be made, and budgeting constraints. This permits extensive or intensive investigation of geographically large or small areas.

Uses of the computer-assisted geographical information system component within the agency include projects in reservoir land planning, water quality planning, regional power facility site screening, flood prediction modeling, and community planning. In these applications, a wide diversity of engineering, natural resource, environmental, cultural, and socio/economic data is integrated to aid land-use decision making. The system has also been used to reference LANDSAT data for land cover mapping

and is being used to create digital soils data bases in cooperation with the Soil Conservation Service.

Data for analysis almost always come from existing sources and expert opinion. The usual source is maps although samples, surveys, and other forms of information gathering may be used. Therefore, the system is an excellent means for integrating data. The paper entitled "Computer Assisted Resource Management" also presented at this workshop, provides a detailed picture of how the land analysis system is used in land management planning (Beeman 1978).

FOREST AND WILDLAND RESOURCES INVENTORY

TVA foresters have been involved in conducting state-of-the-art forest inventories since 1934. Whenever possible, Valley county survey work has been coordinated with the state surveys of the U.S. Forest Service. Although Forest Service survey information is being used extensively, there have been problems with coverage, timing, and consistency. Since three experiment stations are involved with surveying the Tennessee Valley, techniques and schedules differ. Therefore, to get needed information, TVA began surveying the entire Valley in the late 1940's. A number of survey innovations were pioneered over the next two decades. The TVA survey evolved into the forest and wildland resources inventory (Bateson and Ogden 1959). This has proven to be one of the more durable approaches to data acquisition.

Basic Design and Purpose

The forest and wildland resources inventory is a moderately intensive regional survey designed to support resource development programs, primarily for forest industry development. The 125 Valley counties have been arranged into 64 units of from one to four counties. Thus, this inventory is sometimes called the county-unit inventory. Units are fairly homogenous and each contains about 300,000 acres (121,500 ha) of commercial forest land. Sample points are systematically located in each county unit. To achieve consistency, plots are referenced to a square Valley-wide grid. While the total number of sample points may vary from unit to unit, each point usually represents 2,000 acres (810 ha) of water, forest land, or nonforest land. At each forested sample point, permanent plots are established and traditional tree measurements are taken. These data generate information on the timber resource. As a source of timber information, the sample design has proved to be highly satisfactory.

All information is available upon request to industry, ecologists, resource planners, landowners, consultants, cooperating agencies, and resource development groups as either published county-unit reports or as special tabulations.

Because the county-unit inventory approach is technically and statistically sound and because supportive documents and computer processes exist, the methodology with some variation has been used in many additional TVA programs. Systematically located permanent plots have been established on TVA lands and periodically remeasured to supply operational information. The permanent plot inventory has been installed on scores of cooperating ownerships as part of TVA forest management demonstration projects. In an effort to intensify forest land management, plots have been established, data collected, and information processed for all types and sizes of forest properties throughout the Valley.

Integration Through Piggybacking Surveys

With sample points already defined and located proportional to the land cover, the potential of the county-unit inventory as a base for multiresource inventories was immediately utilized. Integration of inventories has been achieved by adding additional surveys to the timber survey in piggyback fashion. Some important information related to natural renewable resources has been collected in this way. Some of the resource surveys which have been added include searches for outstanding phenotypes of commercially important species, hydrologic condition surveys, wildlife habitat evaluations, and vegetative surveys.

Hydrologic Condition Survey

The hydrologic condition survey was started in 1962. A major purpose was to establish the relationships between land use and hydrologic response. At each forest and nonforest sample point, data were collected on land use, damage, conservation practices, vegetation, and soil in addition to the usual site descriptions. The variables were selected from previous work on calibrated experimental watersheds (TVA 1965). With development of streamflow models and with changes in priority, the hydrologic survey could not be further justified. It was discontinued in 1972.

Wildlife Habitat Evaluation

A wildlife habitat evaluation has been a part of the forest inventory since 1963. Almost all the Valley counties have been classified as to the quality of wildlife habitat they contain (fig. 3). The objectives of the wildlife habitat survey are: (1) to determine the present extent and quantity of habitat for seven of the common game species of the Tennessee Valley region, (2) to identify major factors limiting the increase of game populations, (3) to determine the potential for habitat improvements, (4) to record dominant habitat changes, and (5) to predict change. Since large-scale surveys of this kind had not been attempted before that time, TVA wildlife biologists developed the method. Evaluations for each game species are based on the conditions on and about each forest and nonforest plot, on conditions observed while traveling roads and while progressing to the plot, and from aerial photo interpretation. Fieldmen apply guidelines establishing the good, average, poor, or none categories for each habitat factor. The factors considered are interspersion of cover type, quality of cover (including shelter, food, and water) and certain limits on population increases. Since the species differ in their requirements and in their home range, evaluations are made on units of different size:

Deer and turkey	-	1,000 acres (405 ha)
Raccoon	-	200 acres (81 ha)
Grouse and quail	-	40 acres (16 ha)
Squirrel and rabbit	-	10 acres (4 ha)

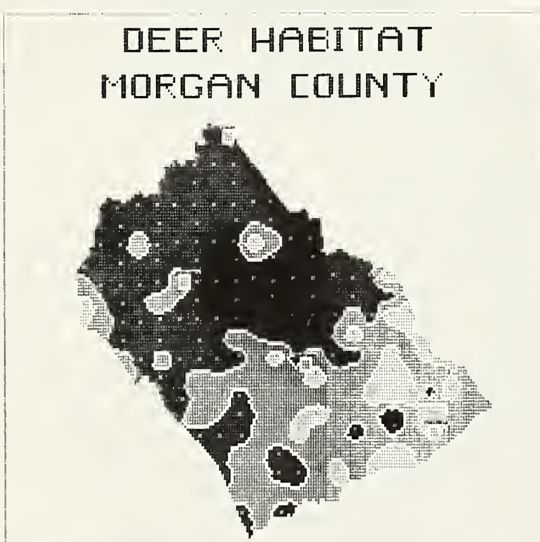

Figure 3.--Wildlife Habitat analysis for deer in Morgan County, Tennessee. Spatial interpolation is based on evaluation at 180 sample points. Dark shading is good habitat; light shading is poor habitat.

Vegetation Surveys

Stocking estimates and reproduction tallies have always been made for tree species during an inventory. In response to recent interest in numerical classification of plant communities, in the total biomass of forest land, and in the need for complete inventories of plant species for environmental assessment, a technique has been developed and tested for a complete vegetative survey on forest plots (McCarthy 1976). Unlike other piggyback surveys, this method does not use the normal field crew. Because of the special knowledge required, a plant ecologist, added to the crew, conducts an independent evaluation. Shrubs, herbaceous and woody ground cover are measured in addition to all trees over one-inch diameter. Soil samples are also taken.

Reassessment of the Forest and Wildland Resources Inventory

During the 15 years of use, the forest and wildland resources inventory has remained constant while internal and external changes have taken place. The recent completion of the first inventory cycle has provided an excellent opportunity to pause and reassess this form of integrated inventory. The modest start in remeasurement has provided the experience needed for thorough reassessment. There are many questions to be addressed, for example: What information is required for administration, management, and planning? Is the information now being delivered relevant to need? Will the expanded responsibility of the Forest Service as a result of the Forest and Rangeland Renewable Resources Planning Act of 1974 satisfy TVA requirements for multiresource information? What opportunities exist for modification and improvement?

At this time the dialogue is continuing. Information systems planning has provided some insight. Strong argument is advanced for each of the alternatives--keeping, modifying, or retiring the inventory. Due to the immense importance of this information to FF&WD, the questions will be quickly resolved, and policies concerning the roles and extent of this particular inventory will be developed and implemented in the most advantageous way.

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Multi-Resource Inventories in Mexico[1]

Miguel Caballero[2]

A summary of renewable natural resource inventories being carried out in Mexico is briefly discussed. The discussion emphasizes forest resources but some information about inventories of arid regions, soils, wildlife, water resources and range is also provided.

INTRODUCTION

The Mexican Republic is a nation with a diversified forest resource. Over its nearly two million square kilometers, cold, temperate, tropical, and arid forest associations occur. Conifers are the taxonomic group of greatest economic importance in the nation, particularly the genus Pinus, which includes about 40 local species. Pines are the most widely used in the nation.

For many years, the need of a nation-wide evaluation of forest resource was evident. In 1951-1952, the first attempt to conduct a forest survey, on a regional basis, was conducted. The Secretariat of Agriculture, with economic support from FAO, carried out an inventory of the State of Mexico, but it was not until 1962 that a national project was finally started, with financial aid from the United Nations Special Fund.

At present, the Mexican National Forestry Inventory, with fifteen years of experience, has developed its own techniques and is entirely financed by the federal government. This agency has provided forest maps and statistics for the 32 political divisions named "States" which comprise the nation. This information is being used for national and regional policies regarding the multiple use of forest lands. Protection regulations and development programs at the federal and private levels are being developed on the basis of the information provided by the National Forestry Inventory.

[1]Paper presented at the Integrated Inventories of Renewable Natural Resources National Workshop. Tucson, Arizona. January 8-12, 1978.

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FOREST INVENTORY TECHNIQUES IN MEXICO

Two basic types of forest resource inventory techniques are carried out in Mexico:

(I) Inventories for Forest Management and,
(II) State or Regional Inventories for Multiple Purpose

(I) Inventories for Forest Management

Forests in Mexico are used by private enterprises, state agencies and by farmers either individually or through different organization schemes. However, most forest management is carried out by Forest Management Unit Incorporations and Industrial Forest Utilization Units. These organizations are also responsible for the majority of forest inventories in the nation.

Management inventories are officially requested as part of the management plan of Mexican Forest Units. These inventories are conducted in accordance with the National Forestry Inventory official regulations (I.N.F. Publication No. 37, 1976).

(II) State or Regional Inventories for Multiple Purposes

This work is basically done by the National Forestry Inventory. One exception is the Michoacan Forestry Commission, which conducted, in 1962, the Michoacan state forest inventory. These studies are, in general, oriented to the establishment of regional policies and rural development programs.

State and regional inventories usually quantify forest lands according to interpretation keys, timber volumes, stand volume increments, mortality, evidence of damaging agents and estimation of damage, etc.

Some remarks on the procedures applied in the Mexican National Forestry Inventory System are summarized below:

Establishment of State Major Forest Regions

The first step to conduct a state forest inventory, is the definition of major forest regions. This activity is done with the analysis of available maps supplemented with information obtained through aerial and terrestrial reconnaissances. Once the state forest regions are established, a sampling plan is prepared for each region on the basis of the economic value and the extension of the forests.

Sampling Schemes

A systematic array of clusters is the most common sampling scheme in state forest inventories. Clusters usually consist of equidistant lines (in the case of temperate forests) or bands (for tropical forests) along which plots are established at regular intervals. The distance from one cluster to another, depending upon sampling intensity, fluctuates from 3,000 to 5,000 meters. The interval between lines or bands usually varies within an interval of 200 to 1,000 meters. Space interval between plots is usually 250m, when working with temperate stands. For tropical forest inventories, plots are contiguous along the cluster bands.

Sample plots for forest inventories in Mexico have been, for most cases, of fixed size, and have a circular shape for temperate forest sampling and rectangular shape for tropical forests. The most common size is $1{,}000m^2 = 0.1ha = 17.84$ meters of radius.

Even though point sampling has successfully been used in some regional inventories, this technique has not been fully adopted.

Field Measurements

As part of the sample data, the following items of information are recorded on each plot: species, dbh, height (total and commercial), and degree of damage. For a smaller sample of trees, bark thickness and increment cores are also obtained. As supplementary data, records of regeneration and ecological conditions of the stand are also recorded.

Data are usually recorded on mark-sense, computing cards. Sometimes data sheets are also used.

Volume Tables

Tree volume tables at regional and state level are made by using Barr & Stroud dendrometers model FP-15. Regression techniques are usually applied in volume table construction. Most Forest Units (enterprises) have regional volume tables for those species of highest commercial value. Tree volume tables for the most important (either in frequency and/or economic value) taxonomic groups in all states have been prepared by the National Forestry Inventory.

Stand volume tables have been successfully used in Mexico. Aerial stand volume tables for experimental purposes were first tried for temperate forests of Durango (Veruette, 1963). For practical purposes, this technique was used later in the Hidalgo state forestry inventory. Terrestrial stand-volume tables were first developed for pine-oak and pine-fir associations by the San Rafael Industrial Forestry Unit (Caballero and Frola, 1976). On the basis of this application, the same procedures were later used on field data from Chihuahua and Durango States (Sosa, 1976). In both studies, the precision of estimated stand volumes was high as obtained through regression analysis by using basal area and height of dominant trees as basic independent variables.

Data Processing

Field data are compiled using a data processing system. Mark-sense cards with field data are mechanically punched and subsequently processed through a series of computer programs, according to the nature and objectives of the inventory. IBM computer systems from the National University and from the Secretariat of Agriculture and Water Resources (SARH) are available for this purpose.

Results

Printed results are organized and interpreted. State forest statistics are reported in technical bulletins and distributed to Federal Agencies, Universities, Public Institutions, and Private Enterprises as requested.

Resource Inventory Maps and Imagery

As part of state inventories, a set of charts is usually drawn by the National Forestry Inventory. Within this set, a forest chart at a scale of 1 to 100,000 or 1 to 50,000 is prepared. This map presents a classification of state major forest regions with their most important forest types.

The Direction General of the National Territory Studies (DETENAL) another Federal agency, is in charge of developing the following seven state maps: topographic, geologic, land use, soil types, potential land use, climates and urban. Maps of this nature are made at a scale 1:50,000 and are available as required, either for institutional or personal purposes.

ERTS and LANDSAT imagery are used by several institutions, such as the National Forestry Inventory and the Mexican School of Forestry (Chapingo, Mex.) for natural resource studies and evaluations. This material has proved to be very useful for broad applications in forestry work.

Several private enterprises provide aerial photographic material at different scales for most important regions of the nation. Much of this material is frequently used for resource evaluations, either for private or official purposes.

C F I in Mexico

From 1970, particular interest arose in Mexico toward the application of the Continuous Forest Inventory. A national convention was conducted in 1971 for the analysis of alternatives which could be applied in this nation. At present, four national meetings on that subject have been conducted. CFI is presently applied in northern Mexico by the National Forestry Inventory. The first permanent plots, established in 1972 in Chihuahua and Durango, are now ready for their first remeasurement, after a five year period. In addition, several other forest units are also applying this management tool with satisfactory results. Among them, the "Loreto y Peña Pobre", "Tutuaca" and "San Rafael" can be mentioned; the latter is the pioneer in the establishment of this technique, and is now ready for a first remeasurement of their permanent plots.

Particularly interesting is the introduction of 3P[3] sampling in CFI work in Mexico. This sampling technique, developed by the U.S. Forest Service, has been successfully studied and applied by the National Forestry Inventory. The Tutuaca Forest Unit, in Chihuahua, has recently completed a report on the advantages of using 3P sampling as a secondary stage in a two-stage sampling scheme. The results, from both the statistical and economic point of view, proved to be highly satisfactory. (Modesto T., R. 1977).

Inventories in Tropical Forests

The Southeastern States--Tabasco, Campeche, Yucatan, Quintana Roo and Chiapas--and the Pacific and Atlantic coastal plains have an important reserve of tropical forests. It has been estimated that tropical forests occupy an area of 19.3 million hectares, which contain 1.038 billion cubic meters of timber, and produce an annual increment of 15 million cubic meters. Red cedar (Cedrela odorata); mahogany (Swietenia macrophylla);gum tree (Manilkara zapota) and many other species occur frequently in the tropical forest type.

Even though several efforts to evaluate tropical forests had been done in the past, the first formal attempt to develop a methodology was started in 1962. To this purpose, a pilot study was conducted in the state of Campeche and the Quintana Roo Territory (Vázquez Soto, 1963). Photointerpretation keys for mixed tropical forests, by using photographs, scale 1:15,000 were successfully developed. By 1966, a sampling procedure of practical application in Mexican conditions was ready for use.

At present, a first general inventory of all tropical forests has been recently completed. Results of this work are now available in the National Forestry Inventory for the different states which have this resource.

OTHER RENEWABLE RESOURCE INVENTORIES

Inventories in Arid Lands

It has been estimated that approximately 80 million hectares (40% of the nation's land surface), are covered by some type of arid or semi-arid vegetation. (Martínez and Maldonado, 1971). These conditions occur mainly in northern Mexico, and to a lesser extent in the central and southern states. Approximately 18 million inhabitants live in these regions. A great portion of that population depends fully or partially upon the local renewable natural resources. Some of the wild plant species are of high economic value, such as jojoba (Simmondsia chinensis); lecheguilla (Agave lecheguilla); candelilla (Euphorbia antisyphilitica) and guayule (Parthenium argentatum).

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[3] 3P: Probability Proportional to Prediction.

In 1963, a first formal effort toward the evaluation of forest vegetation in arid and semi-arid regions of central and northern Mexico, was conducted by the National Institute of Forest Research. This study provided invaluable information as to the distribution, frequency and ecology of the most important species, related to socio-economic aspects of the rural areas where the species grow. (Marroquín et al, 1964).

The natural resources in these areas are presently being studied mainly by the Direction General of the National Territory Studies (DETENAL) and from the forestry viewpoint, by the National Institute of Forestry Research and the National Forestry Inventory. Regional maps of vegetation types are compiled with the aid of satellite imagery and aerial photography.

Field studies in relation to distribution, frequency and potential values for the most valuable species are done by the National Commission of Arid Zones (CONAZA) and by the two Forest Experiment Stations for Arid Regions of the National Institute of Forest Research ("La Sauceda" and "Todos Santos" Experiment Stations).

Wildlife Evaluation

Wildlife studies are made by several universities and research centers. However, the Direction General of Wildlife of the Secretariat of Agriculture and Water Resources is mainly concerned with this task. At present, this work has been directed toward regional evaluations of some of the most valuable and endangered species, such as: migratory birds in coastal marshes, pronghorn (<u>Antilocapra americana</u>) in the state of San Luis Potosí, Baja California condor (<u>Gymnopgyps californianus</u>), white winged dove (<u>Zenaida asiatica</u>), mule deer (<u>Odocoileus hemionus</u>) and big horn (<u>Ovis canadensis</u>). In tropical regions studies of collared peccary (<u>Tayassu tajacu</u>), turkey (<u>Meleagris gallopavo</u>), crocodile (<u>Crocodylus moreletii</u>) and wild cats, among others are emphasized by the Mexican Forest Service. Inventories of this nature are done with the aid of regional cartography, terrestrial and aerial reconnaissances, and field sampling of natural populations.

Recreation Evaluation

The great ecological diversity of the Mexican natural resources, contain areas of high potential value from a recreational standpoint. No specific program has, as yet, been established toward an evaluation of this nature, but the recently established Direction General of Recreation will, undoubtedly, work initially in that direction.

Soil Inventories

Soils are, undoubtedly, one of the most important natural resources of a nation. This is clearly understood by the Mexican Government, which has stimulated different federal agencies to conduct soil inventories of varied nature in recent years. The Direction General of the National Territory Studies (DETENAL), previously mentioned, has the responsibility of preparing maps of present and potential land use. These maps are prepared at a scale 1:50,000.

The Direction General of Soil and Water Conservation has prepared maps and obtained statistics of soils under different levels of erosion. Some other institutions, as the Direction General of Agrology and the Direction General of Agricultural Engineering have also prepared maps of soil types. The National Commission of Arid Zones (CONAZA), on the other hand, works on the study of the soils for the arid regions of the nation.

Water Resource Inventories

The Direction of Geo-hydrology and Arid Zones of the Secretariat of Agriculture and Water Resources is concerned with the detection of underground water strata. Experts in geology, through photointerpretation, determine areas with underground water potential. Supplementary field and laboratory research provides later, of information as to the amount of water and magnitude of fluid recharge. On this basis, plans are prepared for a rational use of water sources. Studies of this nature are conducted mainly in northern Mexico and areas with largest population.

Range Inventory

The inventory of range lands is developed by the Technical Commission for the Determination of Stocking rates (COTECOCA). This agency is supported by the Secretariat of Agriculture and Water Resources. On the basis of ecological divisions, sampling schemes and field work are prepared per region, in order to obtain information regarding: amount and distribution of species with actual and potential grazing value, inventory of natural vegetation, and determination of stocking rates (permissible animal load per unit of area). In addition to the information above, different types of

regional maps, scale 1:500,000, are also prepared by the Commission. Some of these maps are: Distribution of natural climax vegetation, and distribution of actual and potential stocking rates. Supplementary studies of range use and value are also conducted by the National Institute of Agricultural Research (I.N.I.A.) and the National Institute of Livestock Research (I.N.I.P.).

FINAL COMMENT

Mexico is a nation with an important reserve of renewable natural resources. Several of them have been in the past, little or practically unexploited. But some others have been severely used, particularly in the last decades, near the areas of heaviest human concentrations. The Mexican Republic, with one of the highest demographic growth indexes in the world (3.5%) is strongly concerned with a rational and intensive utilization of its natural resources. A multiresource national inventory is today of prime importance toward the goal of improving rural standards of living. The nationals of this country are confident that, based on the results of this inventory, a sound long-term planning can be prepared, to allow tomorrow to overcome the urgent problems of today.

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Multi-Resource Inventories: A Potential of the Forest Survey[1]

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and

Clifford E. Lewis[2]

Abstract.--Cooperative efforts by range, wildlife habitat, and other forest resource specialists have led to inventories of renewable resources besides timber in the Forest Surveys in the South. This paper describes the methodology of these inventories.

INTRODUCTION

With the passage of the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974, attention was focused on renewable forest resources besides commercial timber. Secondary resources such as forage for livestock and wildlife have long been considered important, but no inventory existed comparable to the continuing survey of timber resources by Forest Survey personnel of the U. S. Forest Service. The Forest Survey is delegated nationwide responsibility for collecting and analyzing resource information from forest and forest-related lands. Authority for this activity is contained in the McSweeney-McNary Forest Research Act of 1928 and subsequent amendments. To date, this authority has been exercised primarily with respect to timber and wood products.

The benefits of adding other resource measurements to the Forest Survey were realized as early as 1959, when data on range ownership and utilization were obtained from the survey of the Arkansas Ozarks (Sternitzke and Halls 1962). In the early 1960's, attempts were made to incorporate deer habitat evaluations into the Forest Survey. Moore and others (1960) obtained data on frequency of browse species occurrence in a single Georgia county and classified plants according to deer preference. Procedures based on this work were used to inventory browse resources of more than 4 million acres in 21 north Georgia counties (Ripley and McClure 1963). A more comprehensive habitat evaluation, conducted as part of a 1961 Missouri Forest Survey, estimated herbage and browse production on all Missouri National Forests. In addition to timber and understory vegetation measurements, livestock use, fire history, and several soil and slope measurements were recorded (Ehrenreich and Murphy 1962).

In 1973, the Range Management Research and Forest Resource Research (Forest Survey) Work Units of the Southern Forest Experiment Station conducted a coordinated inventory of timber and range resources in southwestern Louisiana (Pearson and Sternitzke 1974). A comprehensive inventory of all renewable forest resources was begun in 1977 by the Southeastern Forest Experiment Station in South Carolina (Renewable Resource Evaluation Project 1977). This paper summarizes the methods of the more comprehensive Louisiana and South Carolina surveys.

THE LOUISIANA SURVEY

Early in 1973, the Forest Resources and Range Management Research Work Units of the Southern Station initiated a large-scale field

[1]Paper presented at the Integrated Inventories of Renewable Natural Resources National Workshop, Tucson, Arizona, January 8-12, 1978.

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test in 11 parishes (counties) in southwest Louisiana. With a land area of nearly 7 million acres on the Gulf Coastal Plain, the region encompasses most of the longleaf pine-bluestem ecosystem west of the Mississippi River. This ecosystem is probably unexcelled in its ability to produce forage and timber simultaneously.

The objectives of the study were (1) to devise range sampling procedures that could be incorporated into the existing field design of the Forest Survey, and (2) to relate timber resource classifications of the nationwide Forest Survey to associated range conditions.

Forest Survey ground sample locations are permanently established at 3-mile grid intersections throughout every state surveyed. At each forested location, 10 sample points are systematically distributed within a circular 1-acre area referred to as the "sample acre" (fig. 1). Forest Survey uses each point as a center for making a variable plot tally of trees 5.0 inches DBH and larger, and a circle of 6.8 feet radius for measurement of smaller trees.

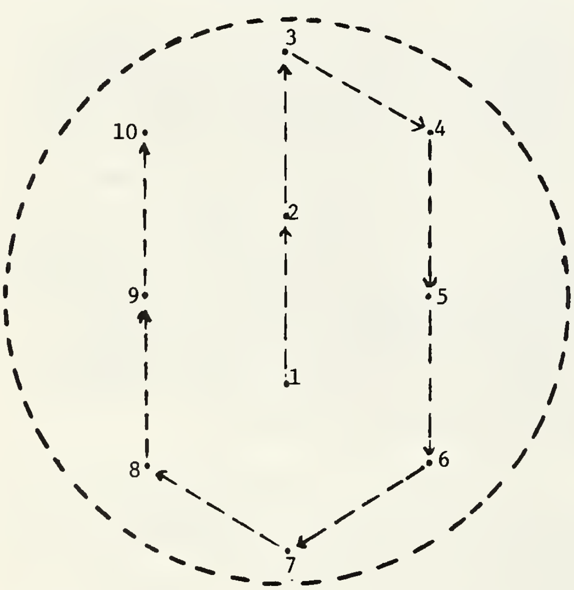

Figure 1.--The standard 10-point-cluster sampling unit of the Forest Survey shown inside the plotless "sample acre" which serves as the unit for certain general measurements or observations.

For range evaluations, circular 9.6 ft^2 plots were marked by center stakes located 10 feet north of points 3, 5, 7, and 9 of the timber survey samples. Each location's 4 range sample plots were thus arranged in a diamond-shaped pattern approximately 114 feet apart.

Before the study began, a 4-day forest-range training school was conducted by range research personnel to familiarize Forest Survey field crews with key plant species and methods for estimating cover, range condition, and utilization. Then Forest Survey team members trained on actual sample plots for 2 weeks. After field training, an intensive 1-day review session reinforced knowledge of understory species identification. However, since only 77 percent of the estimators met the accuracy requirements, estimates of herbage foliage cover were questionable. Inaccuracies were corrected by additional field training.

Foliage Cover

The relative amounts of herbage (grasses, grasslikes, and forbs) and browse (shrubs, vines, and trees) were measured independently on each 9.6 ft^2 plot. Foliage ground cover up to a height of 5 feet was estimated as 0-20, 21-40, 41-60, 61-80, or 81-100 percent. Herbage yield in pounds per acre was estimated by multiplying percent cover by 25.

Botanical Composition

Percent composition of foliage cover was estimated for certain important species or species groups. All other species were assigned to one of four classes: other grasses, other forbs, other vines, or other trees and shrubs. Composition was estimated as one of 4 classes: 0-25, 26-50, 51-75, or 76-100 percent. When a species or group exceeded 25 percent of the botanical composition, dominant species were listed in the remarks section of the field form.

Forest-Range Condition

Range condition refers to the current productivity of a range relative to what a range is capable of producing naturally. Herbage condition was defined as the relationship of current herbaceous vegetation composition to the ecological potential that a forest-range ecosystem is capable of supporting when grazing is excluded.

Plants were classified as "increasers" (those that increase in percent coverage with heavy grazing, at least for a time) or "decreasers" (those that decrease with heavy use). "Unaffected" plants include species that are not affected by heavy grazing or otherwise do not fit the increaser-decreaser classification. Browse was assessed like herbage, but species were classified as desirable, moderately desirable, and undesirable for animal consumption. Desirability is synonymous with ecological ranking.

Plot conditions were divided into 5 classes: (1) excellent--more than 75 percent of the

botanical composition consisted of decreaser herbage or desirable browse and an "allowable percentage" of increasers or moderately desirable browse, (2) good--51-75 percent, (3) fair--26-50 percent, (4) poor--10-25 percent, and (5) very poor--less than 10 percent. The allowable percentage for increasers and less desirable browse species was 5 percent each, with the exception of slender bluestem (*Andropogon tener* (Nees) Kunth), an increaser that provides abundant desirable forage. Slender bluestem was allowed 15 percent. Unaffected herbage and undesirable browse were not considered in determining forest-range condition.

Pine Reproduction

Pine reproduction (trees less than 1.0 inch DBH) was recorded on each plot for the dominant (most abundant or vigorous) species. These measurements were included to show the effects of grazing and timber management on pine seedling establishment.

Burning History, Livestock Presence, and Utilization

Burning history (years since previous fire), livestock presence, and intensity of forage utilization were estimated at each sample location. In determining utilization intensity, herbage and browse components were examined. Utilization categories were: (1) Light--difficult to find grazed plants. Grazing patchy, and generally less than 35 percent of the plants grazed; (2) Moderate--frequently find grazed plants but ungrazed plants are present. Generally 35 to 70 percent of the plants are grazed. Carpetgrass (*Axonopus affinis* Chase) may be relatively abundant, and if so, seedstalks are usually noticeable and average stubble heights are more than 4 inches; and (3) Heavy--generally more than 70 percent of the plants are grazed. Carpetgrass may be relatively abundant, and if so, seedstalks are conspicuously absent and carpetgrass has a mowed appearance. Average stubble height of carpetgrass is less than 4 inches. Threeawn grasses or forbs may be abundant.

Conclusions Based on Louisiana Survey

Basic range resource measurements can be made rapidly and accurately. Range measurements averaged about 35 minutes per sample location compared to about 2 hours for timber measurements.

Identification of species, measurement of cover, and supplementary information on livestock use can be obtained yearlong in the South. But measurements during late winter and early spring may be impossible to get if grazing has removed recognizable vegetation. Measurements would be acceptable, however, except where range has been heavily grazed.

Inaccuracies resulted from incorrect estimates, confusion of two or more plant species, and overlooked plant species. Most of the inaccuracies in herbage estimates were caused by confusion of species. Browse mistakes were largely attributable to incorrect estimates of amount. The range sampling techniques described do not disturb the vegetation.

THE SOUTH CAROLINA SURVEY

While the earlier Louisiana survey added only range data to the timber inventory, the South Carolina survey (still in progress) includes measurements related to wildlife habitat, water, range, outdoor recreation, soils, and lesser vegetation. Land use and burning history are also recorded. As in Louisiana, the standard permanent 10-point cluster is the base for all measurements.

Wildlife Habitat

At each sample location, intensity of utilization of herbage and browse is classified as none, light (less than 5 percent of plants grazed or browsed), moderate (frequent evidence of browsing) and heavy (over 35 percent of plants browsed). Manmade covers such as sawdust piles and other sawmill residue, logging slash, and trash dumps are noted as well as natural cover features such as gullies, caves, rock outcrops, dead trees, and tree cavities. Presence of Spanish moss is recorded since it forms nesting cover for certain birds. Diversity of habitat is indicated by recording the number of forest cover types found within a 2500-ft radius of the sample location.

Remnant pines within a younger forest stand on or adjacent to the sample acre are also recorded. Such remnants (at least 50 years old and 10 inches DBH) are potential habitat for the red-cockaded woodpecker, an endangered species. Red-cockaded woodpecker habitat in live pines is recorded by noting entrance size of cavities. Activity and color of resin flow is also noted, since it indicates recency of occupancy.

Water

Presence of permanent (river, lake, seep) or temporary (flooded) water is noted for the timber stand surrounding or adjacent to the sample location. Depth of any standing water on the sample acre is recorded.

Range

Degree of livestock utilization of grasses, forbs, and shrubs is recorded as none, light (less than 35 percent of plants grazed), moderate (36 to 70 percent grazed), or heavy (more than 70 percent grazed). Livestock fencing in each sample area is recorded as adequate for grazing or unfenced (including inadequate fencing).

Outdoor Recreation

Evidence of human use unrelated to forestry is recorded for each sample area. Specific uses such as hiking, hunting, camping, fishing, and use of trail bikes are noted if definite evidence is found of any of these activities. Presence of trails or roads is noted by type, from active woods roads to game or livestock trails. Posted restrictions of use are noted for the land on which the sample acre is located.

Soils

At point 1 of the 10-point cluster, litter depth, humus depth, and texture of the surface soil are determined. Percent bare ground on the sample acre is estimated to the nearest 1 percent and the percentage of the area that had been subjected to compaction (as by logging or trampling by livestock) is estimated to the nearest 5 percent. Soil structure is determined on compacted areas by comparing the structure of a small soil plug with an illustrated guide.

Slope measurements include percent slope, length of slope from ridge top to the plot center, distance from plot center to the first downslope obstruction that breaks the flow of water and serves as a catchment for soil eroded from the sample area, and distance from the obstruction to the primary water course (river, lake, etc.). If there is no obstruction, the distance from plot center to primary water course is shown. Degree of soil erosion is recorded as none, light, medium, or high at sample points 1, 2, and 3.

Land Use Impact

Sample plots falling in commercial forest are characterized according to their proximity to nonforest uses (such as urban developments, lakes or rivers, agricultural lands, or highways). The closest nonforest uses are noted if they occur within one of three concentric zones around the plot center, from 0 to approximately 833 feet from plot center, 834 to 1665 feet, and 1666 to 2498 feet. These determinations are made from aerial photographs.

Miscellaneous Items

Burning history (number of years since the last fire) is estimated for each forested sample acre. Also the season of the year when sampling occurred (growing or dormant season) is recorded for each plot.

Lesser Vegetation

The greatest amounts of training and field sampling time are required for measurement of understory herbaceous and woody species (including trees less than 1.0 inch DBH). A specialist in plant identification was hired to assist in training field crews. Measurements are obtained on two sizes of circular plot at points 1, 2, and 3 of each 10-point cluster located in forest. A 35-foot-radius sample plot is used to obtain all information on vegetation except occurrence of incidental species, which is recorded for a central 6.8-ft-radius plot.

Height zones[3] are recorded for naturally occurring substories. For example, there might be an herbaceous and woody seedling zone from 0 to 3 ft, a shrub zone from 3 to 6 ft, and a sapling zone from 6 to 17 ft. The number of zones defined and the vertical thickness of each is determined by the presence and growth of various understory species which reflect the history of burning and other disturbances.

Zone percent is the estimated percent of the 3-dimensional volume of each height zone occupied by foliage (excluding low-hanging branches of trees larger than 1.0 inch in diameter).

Plants in each height zone are recorded according to the following *broad species classes:*

- Yellow pines
- Other softwoods (other conifers and soft hardwoods)
- Hardwoods (scrub oaks and miscellaneous)
- Tropicals (Eucalyptus, Melaleuca, Sabal, etc.)
- Shrubs
- Vines
- Grasses and grasslikes
- Forbs and others

Species classes are listed on the field form in order of dominance. *Broad species class percent* is estimated for each species class that occupies at least 1 percent of the total foliage volume stocking of each zone.

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[3]Italicized terms are actual headings on field instructions and data sheets.

Species which are evident and easily observed on the 35-ft-radius plot are recorded in order of dominance within the appropriate broad species class. A coded list of species accompanied the field instructions. After extensive sampling on the 35-ft-radius plot, the 6.8-ft-radius plot is observed carefully and incidental species recorded.

Preliminary Assessment of the South Carolina Survey Methodology

Only preliminary data have been collected and measurement techniques have not been evaluated. Some additional soil measurements have been added. Forest Survey personnel report that plot sampling takes only about 10 percent more time than normal timber-only inventories. Thus, the cost of obtaining the additional resource information is reasonable.

In addition to a broad sampling of soils, topography, vegetation, and other physical features, South Carolina survey data will provide valuable botanical and ecological information. Distribution and frequency of occurrence of individual species can be shown. Distribution of actual or potential habitat for the red-cockaded woodpecker or other wildlife species can be shown. By screening data for those samples with a ground vegetation zone dominated by herbaceous plants the most promising areas for livestock grazing can be selected. Such data could also be used to classify fuels and help predict fire behavior. Potential recreation areas can be located by screening data for a fortuitous combination of topographic, vegetative and water data.

Multi-resource surveys have almost unlimited possibilities for application.

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Multi-Resource Inventory in the Philippines[1]

Severo R. Saplaco[2]

Abstract.--General and specific methodologies of gathering and evaluating information designed to provide data-base for multi-forest resource management in the Philippines are discussed. Emphasis was made at the district level.

INTRODUCTION

Forests are among the primary natural resources in the Philippines. They cover about 40 percent of the total land area of approximately 30 million hectares. Almost 98 percent of the country's forests is government owned (Viado, 1975). The government grants forest concessions or licenses to private companies to harvest forest products, primarily timber. These forest concessionaires or licensees form the core of the wood-based industry in the country.

Generally, the primary concern of the wood-using industry in the management of the public forest is timber harvesting. This concern brought about single-use (timber) management of the country's forests. However, as the population grows, the concept of multiple-use forest resource management may be more economically and ecologically relevant in serving the country's best interest. Evaluating and knowing the productive potentials of all the forest resources will help bring a sound balance between forest resources production and a growing demand for forest products and services.

Prior to implementing multiple-use forest management, an inventory of the forest resources is imperative. The following discussion deals with "state of the art" of forest multi-resource inventory at the district level.

[1]Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.

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FOREST RESOURCES INVENTORY

The primary forest resources considered in this discussion include timber; water; range; land areas for food production, community settlement and recreational sites; and wilderness. Inventory of these forest resources are essential in the overall framework of multi-use forest resources management.

Timber Resource

Timber inventories provide source data for forest management planning, either at the district or national level. Specifically, timber inventory data provide information on available stocking density, stand type and location, regeneration, growth, and mortality (Davis, 1966). These data are necessary in timber stand improvement, silvicultural treatment, and cut scheduling aimed at promoting sustained yield forest operation.

Timber inventories are done using different sampling intensities and designs, depending upon the objectives, cost, population variability, and desired precision of the estimate. Generally, timber inventories in the Philippines are considerably more difficult than in most temperate regions due to the great diversity in forest species. As such, given the same level of precision and comparable physiographic conditions, timber inventories would be more costly. As a general guide, timber inventories aim to estimate the volume of standing trees in a given area as precisely as time and money will premit (Avery, 1975).

The method used in the implementation of selective logging in the Philippines will illustrate specific timber inventory procedures. Within a logging set-up, a fixed 5 percent timber sampling intensity using 0.1 ha (18 m radius) circular plots is made. One plot is

established for each two hectares of the logging area. Trees having 20 cm diameter at breast height are recorded by number, species, diameter class, height up to 30 cm top diameter or to first branch, and volume. The inventory data from the logging set-up are the bases for evaluating forest stand type, stocking distribution, volume for cut scheduling, and overall forest operation programming.

Inventories of extensive forest concessions are conducted by the forest licensees through their forestry department. In general, forest licensees may use varied timber inventory designs and intensities, but basically aim to satisfy a common objective of evaluating their timber stock, while at the same time being cost effective. Available aerial photographs and existing maps of the forest concessions are used as a basis of inventory designs. For preliminary plot locations and distributions, sample plots are often marked on strips laid on aerial photographs or maps. These plots are located on the ground where the timber inventory is conducted using either the 0.1 ha circular plot or the variable radius plot technique.

Water Resource

Forest lands are important sources of water supplies (Satterlund, 1972). However, few data systematically collected to substantiate this statement are available in the Philippines. Water resource values need to be integrated into the overall framework of multiple forest resources management. Therefore, it is essential to have quantitative water resource data from the watersheds.

In 1971, calibration of two pine forested watersheds in the upper Agno River in northern Luzon was initiated (Miner and Gulcur, 1971). These two watersheds typify areas under an "unplanned" management which evolved because the pine forests provide wood for the local mining and construction industries. The river basins also provide water for power production in the Ambuklao and Binga hydroelectric plants. In addition, some irrigation waters come from the watershed and portions of the watersheds provide homes and garden sites for thousands of upland farmers and vegetable gardeners. As such, the watersheds serve various "unplanned" uses.

The instrumented watersheds have a trapezoid-shaped concrete flume with a clock-operated water level recorder. The flume continuously records water level flowing through the stream. The water level data are converted into discharge rate and volume. A weir was constructed earlier in a mossy forest type at Mt. Polis but was destroyed due primarily to faulty design and gage location.

A 20-gage network of non-recording 8-inch standard rain gages also operates on the watersheds. However, today only one of these raingage instrumented watersheds is being monitored. Essentially, these watersheds constitute the few instrumented forested watersheds in the country.

Currently, due to the development of multiuse reservoirs, major river basins are becoming an integral element in the country's economic development. Water resources inventories and valuations which require detailed instrumentations of watersheds are imperative. Therefore, water inventory techniques, instrumentations, and valuations must be developed or adopted, if only to effectively integrate water resource values into the overall framework of multiple forest resources management.

Range Resource

Forest range products are valuable natural resources. Such products are abundant in the country. As such, it would be economically or ecologically sound if these resources were properly integrated into the overall concept of multiple forest resource management. To be able to use range resources soundly, a systematic inventory of the resource base is necessary (Stoddart et al. 1975).

Forest range resources inventories have been insignificant in the Philippines. It was not until 1966 that forest range management was considered an important aspect in resources management (Sears, 1971). Efforts were initiated to study the forest grazing and range problems in a pilot project in central Luzon. Surveys and data collections on the conditions of forest grazing and range conditions were started. Among the relevant range resources inventory activities conducted in the pilot project were:

1. identification of potential range lands,
2. range suitability classification, and
3. vegetation characterization in terms of feeding values, palatibility, grazing tolerance, production, utilization, etc.

Potential forest range lands were identified from existing maps of vegetative cover and land use types prepared by the Bureau of Forestry (now Bureau of Forest Development). Ground surveys were also used for vegetative cover and land use mapping.

Range suitability classification was based on accessibility, forage production, and ability of the area to be grazed on a sustained yield basis without damaging the watershed and other resource values. Suitability for grazing use was determined from ground evaluation of soil stability, topography, forage production, current soil erosion and water availability (Sears, 1971). Currently, range suitability guides for important animals (carabao, cows, and others), which incorporate the above influencing factors, are few and currently, there is a great need for a systematic forest range resources inventory to promote the effective use of forest range resources within the concept of multiple forest resources management.

Food Production Areas

Food production is requisite to a growing population. With an annual growth rate of about 3 percent, the Philippine population is projected to be over 90 million by the year 2000 (Salita, 1974). Forest licensees have potential areas that may be suitable for food (rice, corn, etc.) production. The government recognized these potentials and decreed that forest concession holders develop suitable areas within their concessions for food production (Reyes, 1975). This requirement makes food production a distinct forest land resource use. Therefore, a detailed and systematic inventory and evaluation of the physical characteristics of the designated food production sites are necessary.

Survey crews use standard surveying procedures, concession maps, and aerial photographs in the inventory and characterizations of designated food production sites.

Community Settlement

Within the forest district are communities of growing population. Essentially, community settlements are a distinct forest land resource use that has to be considered in multiple forest resources management. The inventory of the current population in the community and the land use activities of the people is essential.

Community population data are essential in planning current and future community expansion and activities within the forest district. Population data also provide an index of current and future land use activities which may interfere with planned multiple-use forest resources management.

Recent demographic data and actual population census are employed in assessing the community population within the forest district. In many instances, household distribution and population density are determined from actual area population counts and the use of available aerial photographs of the settlement sites.

The current population growth and the resulting increased food requirements of the people combine to make community settlement an important forest land resource use to be considered in multiple forest resources management.

Wilderness Areas

Wilderness areas are generally for wildlife sanctuaries. When Philippine forests were still virgin, they served as abodes of abundant wildlife species. Specific delimitation of wilderness areas did not appear necessary. Now that most of the pristine forest conditions are gone, wilderness areas need to be designated and delimited if only to provide sanctuaries of near extinct and important wildlife species (Sowls, 1971).

Aerial photographs and maps are often used as baseline guides in the demarcation of wilderness areas. Survey crews delimit the ground boundaries of areas designated for wilderness. In many cases, wilderness areas are located on the most inaccessible and relatively pristine segments of the forest district. This locational strategy serves two purposes: (1) inaccessibility of the area discourages unlawful and unnecessary encroachment of wildlife sanctuaries, and (2) illegal forest products harvesting would be limited, if not completely eliminated.

CONCLUSIONS

It is apparent that the forest maintains potential productive resources. These resources can be used optimally, and thereby help meet the demands for products and services of a growing population (Nicholson, 1970). An indispensable element in the optimal utilization of forest-based resources would be a systematic, integrated and well coordinated system to document, evaluate, and inventory all potential productive forest resources. Forest resources inventory data are essential in the overall strategy of effective forest-based resources use, either within a single or multiple-use management framework.

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BLM Intensive Inventory Classification System[1]

Gerald L. Nilles[2]

Abstract.--The Bureau of Land Management in Western Oregon uses a multi-stage land classification and inventory scheme based on the capability of an area to produce timber. The computurized system utilizes FORTRAN Language programs in combination with the COBOL report generating program "SURGE". The information is used for activity and allowable cut planning.

INTRODUCTION

The Bureau of Land Management (BLM) is required by law to periodically reinventory the O&C Lands (Reconveyed Oregon and California Railroad and Coos Bay Wagon Road grant lands) it manages in western Oregon. Until the late 1960's the BLM relied on extensive inventories based on a series of systematic plots installed on a 1.7 mile grid.

As management intensified and the need for more detailed in-place information became apparent, the BLM instituted an Operations Inventory. The Operations Inventory was designed to provide basic information such as size, site class, age, volumes, management needs, etc. for each type island.

While the operations inventory served a useful management need, it soon became apparent that an additional step was needed. What was needed, prior to making management decisions, was to determine what land was capable and available for intensive timber management and what factors would affect the timber production capabilities of the land. We decided, prior to making these determinations, a soil inventory of all O&C lands was necessary.[3] After the soils inventory the BLM then conducted a two step intensive timber inventory on all its land. The first step classified all land by its ability to produce timber. This step was called Timber Production Capability Classification (TPCC). The 2nd step was an Operations Inventory.

SOIL INVENTORY

"The soils inventory was conducted to locate soils and identify their response to resource management" de Moulin _et al_ (1975). On the Medford District the soils inventory resulted in a set of general soils maps[4] and a published soil inventory handbook. The soils report (handbook) contains interpretations of technical and scientific data that is useful as a basis for making land management decisions. The handbook contains a description of the profile, the setting, and the soil behavior of each soil series. This description is followed by mapping unit descriptions of the soil associations. The handbook also contains a section on soil use and management. This section contains charts on engineering properties of soils, interpretive ratings for soil uses, interpretive ratings for selected soil properties and qualities, forest management interpretations, range management interpretations and wildlife management interpretations. The soil maps and interpretive ratings are used as a basis for the TPCC and operations inventory classifications and recommendations.

INTENSIVE INVENTORIES

The objectives of the Intensive inventories, as stated in BLM Manual 5250, - INTENSIVE INVENTORIES, are: Objectives - to provide the manager with detailed, in-place information about the timber production sites for which he is responsible. More specifically, this inventory is designed to do the following:

[1]Paper presented at the workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, January 8-12, 1978.

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[3]The steps set forth are those followed by the Medford District BLM, Medford, OR. The rest of this paper will be based on the procedures followed by the Medford District.

[4]These are soil association maps not detailed soil series maps.

A. Identify and classify the in-place location of timber production classes. (.1)[5]

B. Provide a systematic approach for using timber production classes, along with Management Framework Planning decisions, to establish the timber production base.(.1)

C. Identify within the timber production base the location, acreage, condition, volumes and silvicultural needs (fertilization, thinning, mortality salvage, etc.) on each forest type island, or combination of type islands, that are of sufficient uniformity to be treated as an operational unit.(.2)

D. To provide a systematic approach for recording and maintaining information about the forest to be used in the development of Management Framework Plans, Allowable Cut Plans and short-range forest development and timber harvesting plans.(.3)

In theory .1 TPCC would be conducted and then .2 Operations Inventory would follow. In practice the two steps were done simultaneously to eliminate extensive duplication of field work.

Preparation and Initial Office Procedures

Prior to any inventory work, the Medford District had high-level aerial photographs flown at a scale of 1:80,000. The photos were "blown up" to 1:20,000 scale township photomaps, and overlaid with section lines and ownership. The photomaps were used as the base map for both TPCC and Operations Inventory, however, all preliminary and field typing was done on standard 1:12,000 scale aerial photography.

The efficiency of the field crews was contingent on thorough preliminary work. Photographs, topographic maps, soils maps and type maps were gathered for each township. All existing information which would aid the field crews in the inventory was compiled and preliminary type lines and data were placed on the photographs. Timber sales, recreation areas, scenic areas, buffer zones, etc. were mapped. Sale dates, silvicultural practices, and age and stocking of clear-cuts were also noted. Then tentative boundaries of all operations inventory survey units were placed on the photos. As a general rule the minimum size type island considered for survey was ten acres.

Prior to the start of any "on the ground" inventory, a preliminary road survey was made with the soil scientist. This familiarized the crews with the soil types in the area and helped them identify potential problem sites.

Timber Production Capability Classes-TPCC

This is defined as "the process of partitioning land within the forest boundary into major classes indicating relative suitability to produce timber on a sustained yield basis". This phase of the inventory makes no attempt to resolve conflicting resource uses. Its purpose is to determine which lands are, or are not, suited to sustained yield timber production. Conflict with other resources will be resolved when final management plans are made.

We used the standard definitions for forest, non-forest, noncommercial and commercial forest land used by the National Forest Survey USDA Forest and Range Experiment Station. This left the Bureau with two questions: 1) What constitutes sustained yield timber land? 2) What factors affect the suitability of commercial forest land to be managed for sustained yield timber production?

We followed the guidelines of the Church committee on clear-cutting; i.e., clear-cuts should be stocked within five years. The Bureau established the guideline that partial cuts should be restocked within 15 years. This resulted in the policy that sustained yield timber land should be capable of being adequately stocked within five years following clear-cutting, or 15 years in the case of partial cutting.

There are three factors that affect the suitability of commercial forest land to be managed for sustained yield: 1) location, 2) fragile areas whose timber growing potential could be lost from soil erosion and mass wasting, and 3) reforestation problems. Table 1 is a dichotomous capability classification key.

An area must be difficult or impossible to manage because of geographic location and physical accessibility to be considered

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[5]The numbers refer to sections of the Intensive Inventories Manual, i.e., 5250.1, 5250.2.
(.1) Is the Timber Production Capability Classification - TPCC
(.2) Is the Operations Inventory
(.3) Is the Automatic Data Processing

Table 1.--Capability Classification Key

A. Land is presently or is capable of being 10% stocked with trees	B
A. Land is not presently, nor capable of being 10% stocked with trees	Non-Forest
B. Land is capable of producing commercial tree species	C
B. Land is not capable of producing commercial tree species	Noncommercial Forest (Noncommercial Species)
C. Land is capable of producing 20 cu. ft./ac./yr.	D
C. Land is not capable of producing 20 cu. ft./ac./yr.	Noncommercial Forest (Low Site)
D. Access is limited because of physical location	Adverse Location
D. Access is not limited	E
E. Land is fragile and harvest and/or road building activities must be restricted or excluded to prevent severe impairment of basic timber productivity.	Fragile Site
E. Land is not Fragile	F
F. Environmental factors make successful reforestation of site difficult or impossible within specified time limits	Problem Reforestation
F. Environmental factors indicate successful reforestation may be anticipated within specified time periods without restriction on timber harvest or use of special reforestation techniques	Non-Problem

adverse location. These areas are generally less than 40 acres in size and surrounded by non-forest or noncommercial forest land. The factors that were considered to make an area fragile are slope gradient, ground water, geologic materials and soils. Reforestation problems are caused by high soil surface temperatures, lack of mositure, excessive water, frost, inadequate light, animals, soil movement, debris and brush. Table 2 is a list of timber production capability classes and symbols used by the Bureau.

If an area is determined to be in one of the "problem" classes, then it must be further classified as withdrawn or restricted. An area classified as withdrawn is removed from the timber production base. An area classified as restricted is left in the timber production base but is restricted to special management practices. For example, if a problem reforestation area could be restocked by controlling competing vegetation and shading the seedlings, it would be restricted. If the area cannot be restocked because of extremely rocky soil conditions, it would be classified as withdrawn.

Each district was required to write a supplement to the manual. The supplement described the conditions and problems unique to its area and contains guidelines to aid field crews in using the classification system. Staff specialists in soil, engineering and forest development were involved in the preparation of these supplements.

Table 2.--Timber Production Capability Classes and Symbols

Classes	Symbol
Non-Forest	NF
Forest	
a. Noncommercial Forest	-
- Noncommercial Species	NT
- Low Site	LS
b. Commercial	-
- Problem Site	-
- Adverse Location	AL
- Fragile	-
- Slope Gradient	FG
- Ground Water	FW
- Geologic Materials	FM
- SOILS	FS
- Combination	FX
- Problem Reforestation	-
- Heat and Drought	RH
- High Temperature*	RT
- Inadequate Water*	RM
- Excessive Water	RW
- Frost	RF
- Inadequate Light	RL
- Animal Damage	RA
- Soil Movement	RS
- Debris and Brush	RD
- Combination	RX
- Non-Problem	NP

* One of these may be substitued for RH

Operations Inventory

In simple terms this is an inventory of operational units. It is a detailed type map showing location, acreage, condition and silvicultural needs in each forest type island. It provides "on the ground-in place" information as a basis for scheduling forest management activities.

The operations inventory conducted by the BLM covered all lands, commercial and non-commercial; however, the amount of data collected varied greatly. On non-forest land only those items checked on cards 1&2 figure 1 were recorded. Most immature commercial coniferous forest types were inventoried in detail and cards 3&4 figure 2 were also used. As a general rule, only that information needed to make sound

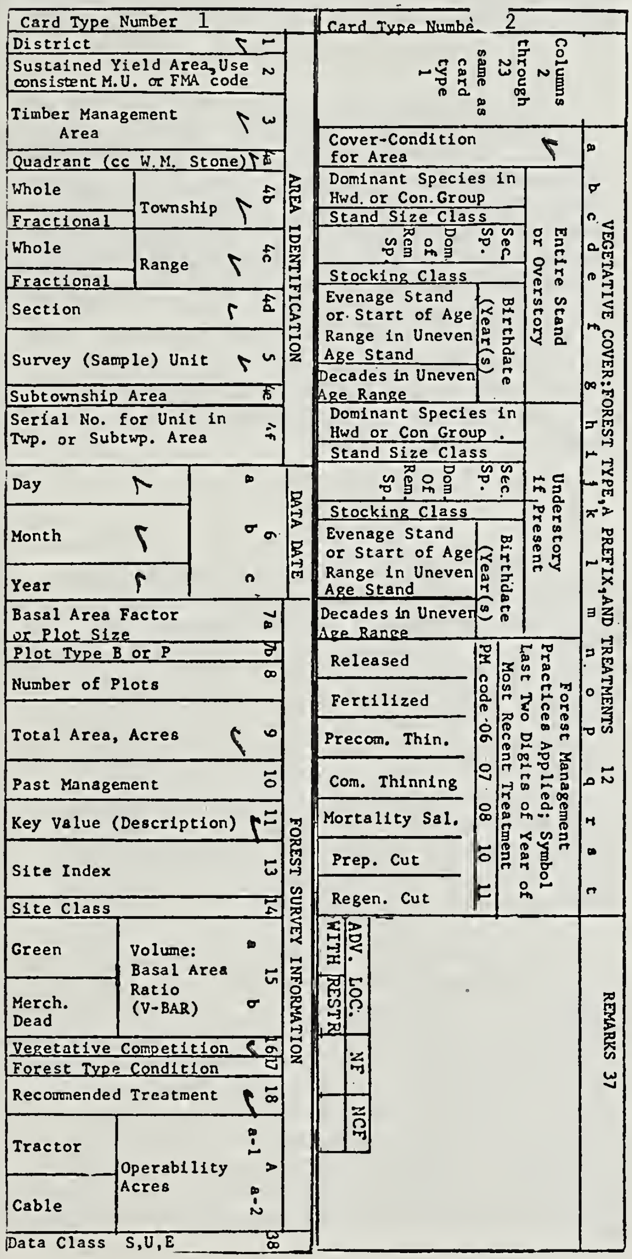

Figure 1.-- Operations Inventory Card Type 1&2

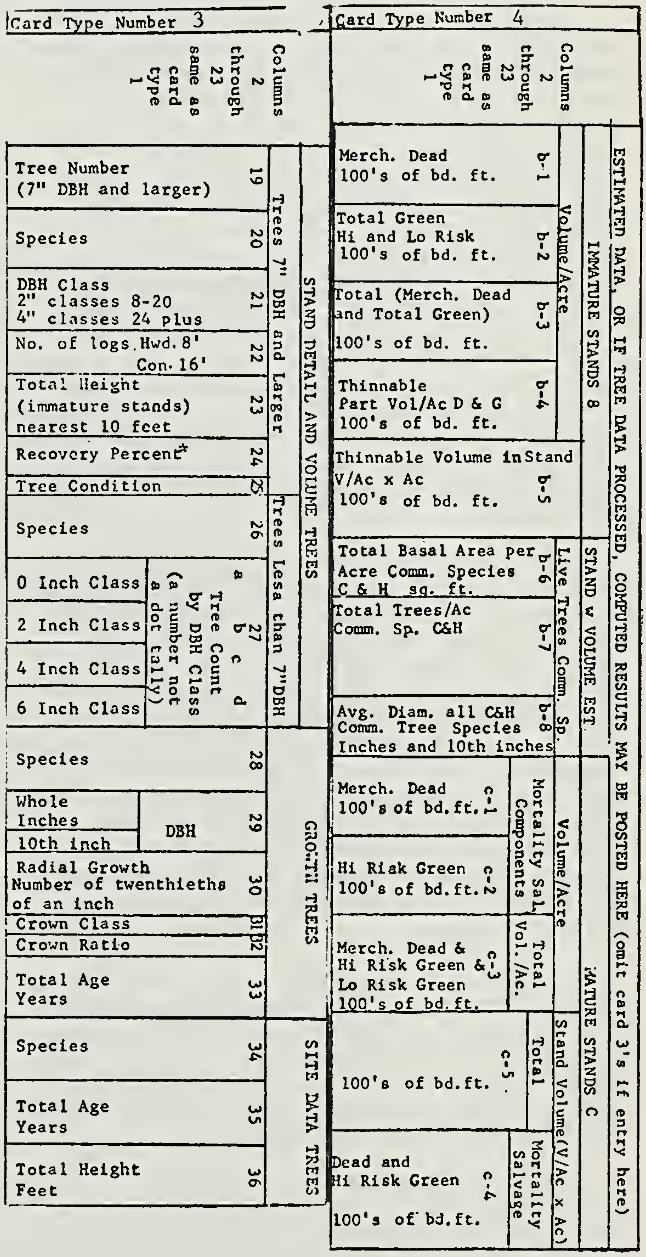

Figure 2.-- Operations Inventory Card Type 3&4

management decisions was collected. For example, if land was withdrawn from timber management by act of Congress, such as the Rogue Wild and Scenic River, very little information was needed, even on commercial forest land. The basic management decision had already been made.

On some units, such as stocked clear cuts, all the data needed was available from existing reforestation records and no field survey was needed.

Most of the items listed on the cards are self-explanatory; however, a few need some explanation. On card type 1, past management (item 10), refers to logging only and the type of cutting that was done; i.e., clear cut, shelterwood cut, salvaged, thinned etc., key value (Item 11), refers to primary land value or use; i.e., timber, recreation, wildlife, watershed, scenic etc., recommended treatment (Item 18), refers to all timber management activities; there were 39 treatment recommendations to choose from, including "no treatment at this time" and "total withdrawal from timber management", data class (Item 38) indicates whether the unit was surveyed, unsurveyed, or estimated. If more than 5 plots were used, data was considered as surveyed. Most of the old growth timber stands were unsurveyed and most immature stands were surveyed.

On card type 2 the TPCC symbol for the area was recorded under item a cover condition. The dates of forest management practices were recorded under item n through t. More than one of these items may have a date; for example, an area may have been precommercially thinned in 1974 and fertilized in 1975. Both dates are important in scheduling future forest management activities. (The date an area is clear cut is recorded under birthdate for entire stand and the species column is blank. When the unit is stocked, the date of planting and species are recorded. We felt once the area was restocked the cutting date was no longer needed.)

Card type 3 was used if units were surveyed. There was a line entry for each tree tallied over 7 inches DBH, and in key punching there could be 50 or more card type 3's. Card type 4 summarized the data collected on card type 3, or, if estimated, the estimated volumes and basal area data was recorded.

After an area had been typed and classified, management had the responsibility of reviewing and accepting or rejecting the classifications of the inventory crew. These reviews were conducted a township at a time, and appropriate staff specialists were included in the review process. The final decision, including the recommendation for restriction or withdrawal, is made by the area manager.

AUTOMATIC DATA PROCESSING

The intensive inventories data was processed using a series of FORTRAN computer programs. The processing ultimately generates plot summary information such as basal area of conifers and hardwoods, basal area of trees over 7" DBH and less than 7" DBH, as well as number of trees per acre, average diameters, volumes, etc.

The resulting plot summary data was stored on magnetic tape for subsequent use in generating reports. The report generator program "SURGE" is a user oriented, laymans language, program which creates internally a COBOL program that generates the report. With a minimum of training the average forester can write his own programs to sort out and list the data he is interested in for a particular activity.

The program is designed to be updated periodically. Since 1974, when the original data was collected, the program has been updated on a yearly basis.

DATA USE

The data can be sorted and summarized for land use planning, allowable cut planning, timber sale planning, annual budgeting and funding, and scheduling of silvicultural treatments. If a manager wants to know how many acres are presently in need of precommercial thinning he can sort it from the recommended treatment data. He has the option of asking for the total acres only, or he can request a line by line printout listing the location, acres and any other data that may aid him in setting thinning priorities. This information can then be used for requesting and budgeting funds of the thinning program.

We are presently remeasuring and establishing new permanent inventory plots for a recalculation of the allowable cut. We used a stratified double sampling technique based on the intensive inventory data. On O&C lands the allowable cut is calculated by master unit, and the number and type of strata varied with each unit. Strata were separated by size and age of timber, recommended treatment, past management, volume per acre, and in some cases species. There are approximately 13 strata in each master unit.

A 90 acre dot grid was used for the double sampling. This is one photo point or data point for each 90 acres of land. The

information for each data point was available from the operations inventory. The variance within the strata was calculated from the available information. The intensity of the sample varied between strata depending on the variance and relative values. A standard error of ± 10% at one standard deviation was used within strata to calculate the number of field plots needed. Existing permanent inventory plots were remeasured where appropriate and new plots were selected from the data points by random numbers. The field plots are a 5-point inventory plot modified from the standard 10-point inventory used by Forest Survey.

The BLM in western Oregon manages 2.4 million acres. There are 5 districts and 12 master units with an annual allowable cut of 1.172 billion board feet. To date the allowable cut has been recalculated on the Josephine Master Unit only, and the field plots have been measured on two others. On the Josephine Master Unit there were 4700 data points and 239 field plots. One hundred forty-one (141) existing plots were remeasured and 98 new plots were established. The standard error was 13% at the 95% confidence level without weighting by strata. It is estimated that the weighted standard error will be less than 10%.

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Decay Amount and Distribution — Some Estimating Methods[1]

Donald D. Munro[2]

Today's forest inventory estimates of volumes, sizes, and qualities of the raw material resource must be reliable and precise. General decay loss estimates based on tree size and age are not sufficient. A method for predicting tree profiles in terms of tree DBH and height is described and progress towards the development of log position decay factors and decay profiles - decayograms - suitable for use in operational forest inventories are documented.

Foresters probably have devoted more time to the study of tree volume than to any other topic, yet there is still concern for better determinations of log sizes, grades and volume. The multiplicity of possible end-uses of a single log in an integrated operation require that the forester provide detailed information regarding the raw material supply. Data for the modern forest inventory must be collected in a manner that permits flexible and comprehensive analyses. Estimates of total volume per acre are not sufficient. The volume of material available in certain sizes and qualities must be estimated with high standards of precision and accuracy. No matter how accurate estimates of gross volume may be however, predictions of soundwood volume will be in error unless reliable methods for estimating decay volumes have been developed and applied.

Regional average decay percentages are of little practical use on a local basis. Often, the variability in decay in one species from different areas is greater than the decay variability among several species from the same area. There is a scarcity of reliable information for local areas. Comparisons of statistics reported often are confounded because of the fact that methods of calculating decay volumes have not been standardized.

Most existing decay loss tables and equations are premised on gross tree volume inside bark with some modification for age class, diameter class, site class or external abnormality groupings. There are very few loss tables or equations which can be used to provide information on the amount or extent of decay in individual logs within trees.

The objectives of this paper are firstly, to briefly review common methods of estimating decay amounts in individual standing trees; secondly, to describe in more detail, progress made by the staff and students of the Biometrics Group, Faculty of Forestry, University of British Columbia in the design and development of analytical techniques to permit estimation of the distribution of soundwood and decayed wood in standing trees; and thirdly, to suggest some approaches which appear to have promise in providing more accurate and precise estimates.

Although decays can be, and often are, described according to their position in the living tree, the same species of fungi can cause decay in roots, butts and stems of living trees. Very broadly, wood-destroying fungi can be separated into two distinct classes. The first class consists of those which decompose all components of wood, including lignin. These are called white-rot fungi. The second class consists of those which decompose only cellulose and its associated pentosans, leaving lignin relatively unchanged until decay is well advanced. These are called brown-rot fungi.

Occasionally some decayed wood is mixed with soundwood in the manufacture of pulp. In addition to cellulose losses due to decay, excessive chip losses caused by brashness of the partially decayed wood are common. Mechanical or hydraulic debarking of decayed wood also results in higher than normal wood losses.

The use of decayed wood for the manufacture of products other than pulp is limited. In most

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instances, decayed wood that reaches a manufacturing plant is eliminated during the manufacturing process. Peeler log grade rules are strict in specifications concerning permissible decay allowances. Usually only a minor amount of heartrot is allowed, and this must be small enough in size to enable the log to be securely held in a lathe chuck.

In general, it can be concluded that increases in the decay volume in trees are almost always associated with increases in DBH. Probably more decay studies have been summarized and presented on a diameter class basis than any other. It should be pointed out that although tree DBH and decay volume are usually significantly correlated, the precision with which amount of decay in individual trees can be estimated from DBH is usually low and extremely variable. A wide range of decay percentages among individual trees of the same DBH class is common, therefore recognition of other factors is necessary.

Most studies have shown that increases in the incidence and volume of decay are associated with increases in the age of trees and stands, although some authors have found this not to be the case. Investigations of the relationship of site quality to decay for a number of species have failed to give consistent results.

Individual trees in mature coniferous stands may be easily segregated into recognizable classes by their possession or lack of certain visible abnormalities indicative of decay, and increased precision in defect estimation is often obtained when trees are classified according to the presence or absence of such abnormalities.

The fruiting bodies or sporophores of fungi, when present, are virtually certain indicators of decay. The absence of sporophores is, of course, no guarantee that decay is absent. Some species of fungi do not produce fruiting bodies until decay is well advanced, others only produce sporophores occasionally, still others produce fragile sporophores which last for only a short time.

Numerous attempts have been made to associate various other external abnormalities such as forks, crooks, frost cracks, mistletoe infections, rotten branches, branch stubs, dead or broken tops, cankers and galls with decay in the living tree. The usefulness of these abnormalities for the estimation of defect varies with the species of fungi, the host species and the local area. It is usually common to find more than one kind of external abnormality or decay indicator on a single tree. When the significance of these abnormalities is assessed singly and in various combinations or groups, increased precision in defect estimation is often possible.

Quantitative information is available regarding relationships between external abnormalities and decay within living, standing trees. However, there is no quantitative information available on the distribution of decay within tree stems and the relationship of this distribution to tree size and external abnormalities. There is clearly a need for the development of an efficient quantitative method to describe the distribution of soundwood and decay volumes within tree stems.

Many authors have attempted to describe tree form and taper and to develop mathematical formulae for the determination of tree volume between specified stump heights and top diameters. Depending on species examined and analytical techniques used, tree form has been shown to resemble a quadratic paraboloid, a cubic paraboloid, a hyperbola, or some form intermediate between a paraboloid and hyperbola.

Matte (1949) found that stem profile of loblolly pine above breast height could be described by the equation

$$y = x\sqrt{ax^2 + bx + c}$$

where

"y" was ratio of diameter inside bark at point of measurement to diameter inside bark at breast height,

"x" was ratio of distance from tip to measurement point, to total height of tree above breast height,

$a + b + c = 1$

and

"a" "b" "c" were coefficients found by least squares analysis.

The British Columbia Forest Service has developed taper curves for the commercial tree species of British Columbia. However, these were constructed by the method of harmonized curves and it is not easy to find a mathematical function which adequately describes them.

The tarif tables of Turnbull *et al.* (1972) are designed specifically for electronic computer applications and are probably the most flexible volume tables available. Volumes can be obtained for 4, 6, or 8-inch top diameters in cubic feet or in board feet. They do not, however, provide the information needed on the distribution of log size and volume within trees.

Honer (1964, 1967) developed a system of equations which permits an estimation of volume of any portion of the tree stem defined by two measures of merchantable height and determination of merchantable volume to any specified top diameter and stump height. His selection of

variables did not however, permit the specification of both a diameter and a length at the same time. An ideal method would permit the determination of log volumes for specified log lengths and diameters. Bruce *et al.* (1968) attempted this for red alder (*Alnus rubra* Bong.) but their technique was not extended to other species.

For several years the Biometrics Group staff and graduate students have worked together more or less continually on the development and refinement of a tree taper estimating system to provide the basis for the development of a methodology to estimate position and amount of decay and soundwood in standing trees.

We have been fortunate to have access to an excellent data source maintained by the Inventory Division of the British Columbia Forest Service. Since 1952, they have been engaged in a program to collect stem analysis information for tree volume tables, decay loss factors and site index curves. These stem analyses are carried out in accordance with strict standards and include all field measurements necessary to define decay boundaries and tree taper from ground level to tree tip. To date, more than 32,000 individual tree records have been maintained.

Since the beginning, our efforts have been concentrated on developing an equation to provide estimates of stem diameter inside bark at specified heights and conversely, estimates of heights at which specified stem diameters occur, in terms of the tree parameters DBH and total height. Initially a function of the form

$$d_i = D\sqrt{\beta_0 + \beta_1 \frac{h_i}{H} + \beta_2\left(\frac{h_i}{H}\right)^2} \qquad (1)$$

where

d_i = bole diameter inside bark at location "i"

h_i = height above ground level to location "i"

H = total tree height

D = tree DBH outside bark

was selected and tested on a sample of 369 western hemlock (*Tsuga heterophylla* (Rafn.) Sarg.) trees, using linear least squares techniques. Comparisons of actual and estimated diameters showed some bias in the form of an underestimation of diameters, especially near the butt, where flare is often excessive and near the tree tip, where form is usually conical. Expansion of the equation to a fifth degree polynomial eliminated some, but not all of the bias. The best equation provided estimates of upper stem diameters inside bark with a standard error of estimate of ±3.3cm (±1.29 inches) using measures of DBH and total height.

Despite the rather low standard error of estimate, the equation selected could not be used directly to obtain accurate estimates of volumes of logs within standing trees. The biases in diameter estimation near the butt and tip made it necessary to use a separate equation to estimate total tree volume and to adjust volumes derived from the taper function to equal those derived from the volume function. The simplest method of adjustment is to compute the gross volume of the tree to the standard of utilization of the tree volume function by accumulating all log volumes estimated by the taper function. This volume is then compared with the tree volume estimated from the volume function and any difference in the two volumes is pro-rated on a percentage basis over individual log volumes calculated from the taper function. This adjustment ensures that the total volume calculated from the taper function will equal the total volume calculated from the volume function.

The test results were considered to be satisfactory enough to warrant test applications to other species. A sample of more than 7,000 tree records were selected for all the commercial tree species and equations of type (1) were fitted with conditioned linear least squares techniques. Results were satisfactory, showing standard errors of estimates of diameters ranging from a low of ±0.8cm (±0.32 inches) for birch (*Betula* spp) and a high of ±5.9cm (±2.34 inches) for Sitka spruce (*Picea sitchensis* (Bong.) Carr.).

A brief description of the system, its potential usefulness and the equation coefficients were published in a local trade journal and several small and large private forest companies incorporated the system into their forest inventory compilations.

Following acceptance of the initial system, efforts were concentrated on the development of a method that could be used to estimate volume and taper simultaneously. Clearly the adjustment procedure described earlier is imprecise and also biased. A compatible system - i.e. one in which total volumes obtained from both a volume equation and a taper equation are identical offers many advantages.

Two types of systems were considered: volume-based in which a compatible taper function is derived from a tree volume equation, and taper-based in which the tree volume function is derived from a taper equation. Both systems proved workable. Taper functions were derived from most of the common formulae used for tree volume estimation and several taper functions were developed which could be easily integrated to estimate total tree volume.

However, despite the use of weighting and non-linear estimation techniques, no method

proved entirely satisfactory. Biased estimates near the butt and tip still presented problems; nevertheless, demonstration of compatibility proved to be a significant step forward. It became obvious that any further work would have to be directed towards reducing the bias of estimates near the butt and tip while retaining the features of compatibility.

A final study was mounted to develop a system incorporating all of the features found desirable in the many functions tested earlier. This time the entire data bank of over 32,000 tree records was utilized.

Computer plots of numerous tree records were examined and it became apparent that the inflection point in most tree profiles occurred in the same relative position. Subsequent analysis showed that for all species, the inflection point ranged from 20 to 25% of the total height above ground level. The possibility of using two separate taper functions, one for the portion of the bole above the inflection point and one for the portion of the bole below the inflection point was examined. To do this it was necessary to ensure several conditions; firstly, the lower equation must represent butt flare, and pass through diameter inside bark at breast height; secondly, the upper equation must accurately represent tip profile and give a zero diameter estimate for total tree height; thirdly, both equations must join at the inflection point continuously (i.e. their first derivatives must be equal at the inflection point). The complicated nature of the functions finally selected necessitates the use of an electronic computer. Common desktop or pocket calculators do not yet have the capability to evaluate them.

The test results show that the final system is remarkably precise and accurate (Table 1). Standard errors are very small and bias is nearly negligible over the entire length of the bole. Reliable estimates of gross volumes and sizes of logs of specified dimensions in standing trees can be obtained with this system. In fact, the test results have proved so satisfactory that the authors have named it the "whole-bole" system. The British Columbia Forest Service has indicated

Table 1.[1] Precision and bias in the estimation of *d*, *h*, and volumes for coastal immature Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco) and broadleaf maple (*Acer macrophyllum* (Pursh))

		Standard error of estimate (SE_E) and bias[2] of *d* at							
Species		1 ft	4.5 ft	0.2 HT	0.4 HT	0.6 HT	0.8 HT	1.0 HT	Total
Douglas-fir	SE_E, in.	1.34	0.38	0.56	0.57	0.60	0.65	0.00	0.72
	Bias, in.	0.85	0.00	0.01	-0.06	0.00	0.04	0.00	0.13
Maple	SE_E, in.	1.01	0.07	0.26	0.38	0.44	0.40	0.00	0.49
	Bias, in.	0.79	0.00	0.00	0.05	0.04	-0.02	0.00	0.14

		Standard error of estimate (SE_E) and bias of merchantable *h*(*d*=4 in.) for the following DBH classes:				
Species		0.0-10.0	10.1-20.0	20.1-30.0	30.1-40.0	Total
Douglas-fir	SE_E, ft	2.17	2.90	3.32	3.39	2.62
	Bias, ft	0.74	-0.10	-0.77	-3.17	0.22
Maple	SE_E, ft	2.14	3.11			2.24
	Bias, ft	0.52	-1.02			0.37

		Standard error of estimate (SE_E) and bias of total volume for the following DBH classes:				
Species		0.0-10.0	10.1-20.0	20.1-30.0	30.1-40.0	Total
Douglas-fir	SE_E, ft^3	0.98	4.92	12.53	13.44	4.94
	Bias, ft^3	0.16	0.63	1.05	-5.31	0.39
Maple	SE_E, ft^3	0.65	1.80			0.83
	Bias, ft^3	0.17	1.03			0.25

[1] Demaerschalk & Kozak (1977)

[2] Positive bias represents underestimation, and negative bias represents overestimation.

its intention to incorporate the system, province wide, into its stumpage appraisal system.

Somewhat paralleling the work leading to the development of the whole-bole system, there have been attempts to develop a compatible system of tree and log position decay estimating functions. Initially, testing was carried out on the same 369 western hemlock trees used in the original taper studies.

The development of a tree decay estimating function is relatively straight-forward. The use of dummy variables in linear least squares analysis enables examination of the effect of external abnormalities (e.g. conks, scars, dead tops, rotten branches, etc.) thought to be associated with decay.

For example, an equation such as (2)

$$\text{Decay \%} = -4.136 + .511\text{DBH} + 22.2\ (\text{conks}) + 10.98\ (\text{scars}) + 4.64\ (\text{dead top})$$

developed for the 369 western hemlock trees can be used to estimate decay as a percentage of total tree volume with a standard error of estimate of ±19.5% by simply substituting the numerals "1" for each of the indicators present and "0" for each of the indicators absent.

On the other hand, the development of a system to estimate decay amounts in specified portions of the tree bole is not at all straight-forward!

Examination of the position of the decay columns within the 369 western hemlock trees showed that for all decayed trees the average column of decay was situated in the middle portion of the trunk. Decay did not extend downwards to the ground level or upwards to the point of merchantability. The location of the main decay column suggested that logs in various positions within the tree would not have the same decay volume or decay volume percentage. From the average location of the rot columns it could be expected that logs in the mid-section of the tree would be the most defective, while butt logs and top logs would be relatively less decayed. Analysis of the individual cut sections showed this to be true. Decay percentage increased from the butt logs to the third log, decreased from the fourth to seventh log and then increased slightly to the tree tip. The third log in the tree was the most defective averaging 21.4 per cent decay, however, the second log contained the largest cubic foot volume of decay.

At first consideration, it might seem logical to develop a function to estimate log defect in terms of the top diameter of the log. This is not sufficient, however, because the position of the log within the tree is an important criterion in the determination of the amount of defect likely to be present in that log. A log with a small top diameter could originate from the top of a large tree, the middle of a smaller tree or the butt of an even smaller tree. As pointed out earlier, each of the above positions requires a separate decay loss factor. It is necessary, therefore, that any function developed incorporate some measure of log position as an independent variable. The manner in which log position is indicated is also important. In order to provide maximum flexibility, it is necessary that the equation be adaptable to provide estimates for logs of any given length. A measure which determines log position relative to total height of the tree can be readily used to provide such flexibility. The simplest and probably most efficient expression is h/H where "h" is height above ground of the top of a given log and "H" is total tree height. This fraction can be used to specify the exact position of the top of a log in any tree for which total height is available.

An additional measure needed to develop a predicting equation is the DBH of the tree. The hypothesis then can be stated that the defect percentage in any log is a function of the tree DBH and log position expressed as h/H. To this must be added those external indicators which proved to be significant in the development of the tree decay factors. Utilization of the log position indicator h/H permits the estimation of percentage decay in a tree to any given height.

The equation developed with combined best precision with least bias was one which expressed decay from ground level to a specified height (h) as a percentage of gross total tree volume. It was[1]

(3)

$$\text{Decay \%} = -9.236 + 18.44\ (\text{conks}) + 8.733\ (\text{scars}) + 2.906\ (\text{dead top}) + .0084\ (\text{DBH}^2) + 28.60\ (h/H) - 16.11\ (h/H)^2$$

Standard errors of estimate ranged from ±0.39 m^3 (±13.7 cubic feet) in butt logs to ±.003 m^3 (0.1 cubic feet) in top logs. The equation has a significant bias and a relatively large standard error when used to estimate decay amount in the first 5 m (16 foot) butt log; thereafter however, bias is acceptable and precision improved.

Having demonstrated the feasibility of the technique, a new sample of 628 western hemlock trees from a different geographic area was

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[1] external abnormalities assigned value "1" if present; "0" if absent

selected and analysed. Patterns of decay were found similar to the first 369 trees, but amounts of decay were greater. Standard errors of estimates and biases were almost identical.

Examination of the differences between whole tree volume percentage decay and log volume percentage decay revealed potentially serious practical implications. These differences range from +4.3% to -15.2% depending entirely on the position of the log within the tree. In each of the analyses, the application of the whole tree decay loss factor would have resulted in an under-estimation of the merchantable volume of usually higher quality and higher value butt logs, an over-estimation of merchantable volume of logs from the mid-section of the tree and an under-estimation of merchantable volume of generally low quality and low value small logs from the top of the tree.

Although the above analyses demonstrate that log position tree decay factors can be derived, there is still a great deal of work remaining before such a system can be implemented operationally. From the practical point of view, a knowledge of the dimensions of the decay in the log is more useful than a percentage figure relating to volume.

Early in our analysis we attempted to develop a procedure to describe the physical dimensions of the decay column (e.g. lengths, widths) within the tree. We were not successful for several reasons; mainly however, because at that time the compatible tree profile system had not been perfected.

Currently, we are re-examining this initial work with the objective of developing a system to describe the entire decay profile within the tree. A probabilistic approach based on the excellent work carried out by Hamilton (1974) and Hamilton and Brickell (1977) appears to have merit. In October, 1977 the first computer generated decay profile graph - a decayogram - was produced.

Probably the most difficult problem to deal with is the highly variable nature of decay organisms and the manner in which they attack and destroy the wood in living trees. Different species of fungi attack different species of trees in different geographic locations in different ways. Clearly, any estimating system which purports to provide useful unbiased estimates of both the amount and position of decayed wood in standing trees must be predicated on a sound biological understanding of the nature of the decay organism and the way in which it interacts with its environment.

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A Practical Approach to Biological Inventories for Ecological Baseline Studies[1]

James B. States[2]

Abstract.--A number of historical and functional reasons are given for the difficulty encountered by environmental scientists and resource managers in coping with the demands of NEPA. A recent convergence of professional thinking toward resolving these difficulties is outlined in the form of a step by step approach to designing ecological baseline studies for maximum impact upon energy development decisions.

INTRODUCTION

The statement of objectives for this workshop points out that increasing demands placed upon our natural resources make it "imperative that we develop efficient objective methods of determining the resources that we have." This is not a new perception. In fact, this same perception had much to do with the framing and passing of the National Environmental Policy Act in 1969. With that act there came into being a requirement for a new type of resource inventory to be used as a basis for environmentally sound decisions over a wide variety of pending federal actions. Such inventories have commonly come to be referred to as baseline studies.

As environmental scientists and resource managers looking back over the last seven years of NEPA, we have to admit that much of the information gathered in the course of such studies was of little use to decision-makers, and even the useful information was often ineffectively used in the decisionmaking process.

There are a variety of historical reasons why this should have been so and why, as a result, little progress has been made over the last seven years. This paper reviews some of these reasons and identifies a recent convergence of professional thinking about how to do the job better. Using this new perspective as a basis, the primary objective of the paper will be to suggest a new approach to designing more responsive (and responsible) baseline studies. From this point on, although the principles apply to any baseline study, I will direct my remarks specifically to ecological baseline studies.

HISTORY

One reason for our lack of progress in effecting environmentally sound decisions has been the internal squabbling among environmental scientists. In general we agree that our science should have a large influence on such decisions but there has been a lot of controversy over who should be providing that input and how. This controversy has surfaced in a number of forms -- academic versus applied ecologist, basic research versus mission-oriented research and "pure" versus applied science. The sad result has been that no one has taken clear responsibility for moving the science forward. Many academic environmental scientists have shown a strong aversion to research into the effects of environmental pollutants because they viewed it as "applied" rather than basic research. Industry, on the other hand, has generally refused such investigations as being basic research and therefore the responsibility of academic institutions. And consulting ecologists, although clearly seeing the need for such research, have largely been unable to secure the funding necessary to do it themselves.

We have been led into this state of affairs by a commonly voiced but mistaken assumption that there is in existence a large body of knowledge which, if effectively applied by trained practitioners, will enable us to avoid serious ecological damages from industrial developments. The fact is that there is not presently a sufficient information base to

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be thus "applied". None of us knows enough about the response of free-living populations to natural stressors, much less man-induced stressors, to be able to make accurate assessments of impacts across the board. Another stumbling block in the way of environmentally sound decision-making has been that NEPA caught us unprepared. The companies and agencies charged with carrying out the law generally had few or no ecologists on their staffs and those they did have, or they consulted with, were ill prepared to meet the challenge. Furthermore, the decisionmaking machinery that was swung into the breech was often geared to an engineering mentality of technical fixes and shortest possible time frames that left little room for input from carefully designed environmental studies extending over several seasons.

In a number of ways, often unwittingly, biologists contributed to, rather than reduced, the state of confusion. Because they were unprepared for the complicated process of combining the best available biological information with detailed engineering plans as a basis for predicting impacts, they tended to fall back on the existing methods of data gathering and analysis instead of concentrating on new techniques. In the absence of generally accepted standards for such data gathering, each scientist tended to do his own thing, thereby minimizing the degree to which results from one project could be generalized to another. Moreover, there was a tendency for environmental scientists to hang on to some notions from their academic backgrounds which leave them practically hamstrung. For example, there persists to the present a notion that an objective scientist is only an information gatherer and interpreter whose responsibility ends with presentation of his results in pedantic technical reports. There is a corollary notion that it is not scientifically "nice" to become advocates for our data, taking responsibility for presenting our results in the most effective way and plugging them in through the most effective decision channels in time to influence decision outcomes.

And finally, even our fervor to do the job right sometimes gets in our way. For example, one of the most environmentally important decisions with regard to new energy developments is that of alternate site selection. Yet ecologists frequently have little to say in this decision and one reason may be that historically they have insisted upon intensive site specific studies of a year or more in duration at each siting alternative before they can render a "sound" decision. The chances are that a quick but careful survey of each alternative by some standardized procedure, would reveal most of the cogent reasons for selecting one site over another.

SUGGESTED PERSPECTIVE

For all these reasons and more there has been much thrashing about on how to perform the special kind of inventories we may term socio-environmental assessments, particularly those for proposed energy developments, and especially that part of the assessment referred to as an ecological baseline study. As part of a larger attempt to bring some order to the confusion my firm, Ecology Consultants, Inc., has been working on a project for the Western Energy and Land Use Team of the Office of Biological Services, U.S. Fish and Wildlife Service. The objective of the project is to "clarify and standardize the purpose and practice of ecological baseline studies in the Western United States." This was to be done by developing a user's manual for designing such studies. It has been a conceptually exciting and intellectually demanding effort, one that has led us through a great volume of literature and an extensive collaboration with professionals all across the country.

Along the way the project team became increasingly aware of an overwhelming convergence of thought among practising environmental scientists. It's as if we are all shaking our heads free of the cobwebs and confusion and, by a wide variety of routes, arriving at the same conclusions as to what the problems are and what needs to be done about them. In the course of reviewing these trends a number of perceptions were arrived at. These were then developed into an operational definition of what ecological baseline studies are and a summary statement of assumptions which were felt to necessarily underlay the design of better ones.

Operational Definition

For the purposes of the manual, an ecological baseline study is <u>any investigation conducted prior to the "breaking of ground" in order to provide an ecological basis for decisions on whether, where, and how to develop energy resources in the western United States.</u> The scope of study may range widely, from qualitative inventories conducted by natural resource managers to exhaustive quantitative studies of specific energy development sites undertaken by industry in compliance with federal and state regulations. The results of an ecological baseline study describe the existing ecological conditions and trends in the potentially affected region, providing a reference "baseline" from which environmental scientists can (1) predict the effects of the proposed action and recommend alternatives, (2) define appropriate mitigation measures, and (3) design programs to monitor the accuracy of

predictions and the effectiveness of mitigations in the future.

Underlying Assumptions

One of the reasons for the lack of thoroughness and consistency among ecological baseline studies is that there has been no common set of understandings from which such studies were conducted. The following assumptions represent an abbreviated synthesis of the current thinking among environmental scientists as a conceptual framework or perspective from which better baseline studies may be designed.

Environmental Scientists Responsible for Tying Ecological Information to the Decisionmaking Process

Environmental biologists are now showing a growing awareness of their failure to anticipate the needs of the decision-making process. They are starting to push for better ways of implementing their information into that process. There is an increasing awareness that ecological baseline studies should provide a good basis for the prediction of environmental effects and that these effects should be "...described in terms that will make sense to the reviewers of the assessment. In particular, these effects should not be described exclusively in terms of chemical, physical, or biological parameters. Rather, potential impacts should be addressed in terms that relate to their implications to social well-being, land-use potential, or to changes in resources or characteristics of the environment that may be considered worth preserving, conserving or enhancing." (Dickson et al., 1975)

The Need to Provide Judgments on the Biological Significance of Anticipated Effects.

It would be irresponsible for us to continue to duck the issue of biological significance for effects we predict from proposed actions. Even though it may leave us more exposed to legal action, it is the environmental scientist, not the decisionmaker, who is in the best position to make such judgments. In a recent workshop on this subject it was concluded that "an impact is significant if it results in a change that is measurable in a statistically sound sampling program and if it persists, or is expected to persist, more than several years at the population, community or ecosystem level (Sharma et al., 1976)." The social "acceptability" of such effects is a judgment to be made in each specific case on the basis of relative costs and benefits to society.

Applying Better Science to Environmental Problems

The principal focus of this workshop is "what" and "how" to inventory. However, the answers to these questions must be preceded by an answer to the question, Why do an inventory at all? As is often the case when a science finds itself having difficulty providing the needed answers, we find we haven't been very careful about asking the proper questions. Thus the convergence of opinion identified during the course of our study has been that the complex problems we face can best be solved by taking a systematic approach that resolves into three basic steps:

1) Ask the right questions. Find out what really needs to be known to facilitate environmentally sound decisions.

2) Translate the information needs into specific statements of objectives for a study program and apply the best techniques science has to offer in fulfilling these objectives. Whenever possible, the objectives should be met by the framing of good, testable hypotheses about how we think industrial developments may affect local ecology and the design of elegant experiments to test our predictions.

3) Put the information thus obtained, the information needed by the decision-makers, into its most communicable form and plug it in through the most effective decision channels in time to maximally influence decision outcomes.

Needed-a New Perspective From Which to Design Ecological Baseline Studies

If we accept that the central purpose for any ecological baseline study should be to obtain the best possible input to energy development decisions, and that to do so can become extremely complicated, then a systematic perspective for accomplishing these steps is sorely needed. There is an emerging consensus that the selection of "what to measure" in ecological baseline studies should be approached from a holistic perspective. This approach has been eloquently advocated for some time by systems ecologists (Van Dyne, 1966) but is only now gaining wider acceptance (Bella and Overton, 1972; Odum and Cooley, 1976).

A natural outgrowth of this trend is a renewed interest in using conceptual models to organize thinking about which parameters need most to be measured. A case is strongly argued by Cooper (1976) that two strategies for environmental protection are open to us. The simpliest is to monitor the behaviors of specific indicators to assess damages and then

to compensate for them. However, once experienced, the losses may not be compensable (extinction of a species, for example). Thus the cost of being wrong via this feedback control is too costly. An alternative to the feedback "experiencing" of damages is a "feed forward" or predictive control process. This requires the development of a valid functional model of biological systems, monitoring the critical aspects of the physical and biological environment and then anticipating the behavioral characteristics of the system under anticipated perturbations. Development of conceptual models by which we can formulate, communicate, and improve our understanding of ecosystem functioning has been recognized by a wide variety of authors as an essential early step in this foresightful decision-making process.

A RECOMMENDED HOLISTIC APPROACH

The output of our project is a manual that sets forth detailed procedures under a series of major steps in designing ecological baseline studies from a holistic perspective. Fundamental to this approach is the understanding that ecological baseline studies do not take place in a vacuum.

The Energy Development Program

For our purposes, an ecological baseline study is treated as an integral part of a larger whole termed an energy development program. This program is definable as a series of project phases which are punctuated by major decision milestones. In order for the program to proceed on schedule several kinds of basic information must be developed during each project phase and provided to decisionmakers in advance of the final date for each decision milestone. This information is provided through a series of study programs conducted by the development team. In the present case three kinds of study programs are identified: the engineering study program, the ecological study program and socioenvironmental study programs other than the ecological program.

Several points crucial to the holistic perspective are identified here but should be kept in mind throughout the discussion to follow:

1. If our purpose is to maximize biological input to the decision process it is critical that the ecological study program be timed to maximize the impact of study results upon decision outcomes.

2. There is a great need for integration between study programs. For example the technical/engineering plans tell the biologist where he needs to look for problems; the hydrologist can tell him whether or not he needs to worry about contaminated ground water coming to the surface down-dip from the development; and the sociologist will have something to say about the significance of increased hunting pressure on game animal populations.

3. There is a continuing need for resolving one of the most serious deficiencies of past and current baseline studies. Most baseline studies to date have overemphasized the "site description" function of baseline studies, generating long lists of species and pounds of quantitative and semi-quantitative data tables that may help overdescribe what is there now but which are useless in evaluating whether or not impacts occur if the development ever comes on line. To the maximum extent possible, baseline studies ought to provide statistically verifiable results that will be useful in separating man-induced from naturally occurring biological changes should the energy development be approved. Another way to put it is that baseline studies should be designed so as to provide data that are upwards compatable with likely long-term monitoring programs.

Major Steps in Study Design

With the above perspective as a starting point the manual provides detailed advice on how to design better ecological baseline studies. These can only be briefly described here.

Define the Decisionmaking Framework and its Information Needs

Each energy development progresses within its own unique decisionmaking framework. This framework consists of the plans of the developer and his technical project team (including biologists), the concerns of agencies and other interested parties which will provide commentary and effect decisions about what the project team proposes, and the legal and informal procedures and protocols by which decisions will be reached.

It is only within the context of the decisionmaking framework that an ecological study program responsive to the needs of the decision process can be defined. A point to be emphasized is that a process of "open planning"

is the key to success. Developers who want to keep their project under wraps until it is cast in concrete and regulatory agencies who don't wish to give away their position on key development issues are not operating in the public interest. The effectiveness of study programs will be in direct proportion to the degree of involvement of all interested parties in the early identification of what information is needed and how best to go about getting it.

The following activities for documenting the decisionmaking framework are described in the manual:

1) determine the dimensions of the project spatial characteristics and major activities,

2) determine time dimensions,

3) identify a geographic/political region for the development,

4) determine the decisionmaking process for the project,

5) identify major decisions and who will make them, and

6) identify other parties potentially involved in decisions.

Define the Purpose, Goals, and Objectives of the Ecological Baseline Study

The next major step in designing the study program is for the project team to work on an open-planning basis with all interested parties in translating the generalized information needs, stated as questions, into specific statements of purpose, goals and objectives to provide answers. In this framework the objectives are stated so as to form a functional "bridge" between the defined information needs and the specific methodological elements of the study program designed to fulfill those needs.

Define the Environmental Systems of Interest

Based on the objectives of the study program (and to some degree exercising some feedback control over how those objectives are stated) it is necessary to place logical limits on the geographic space and the time dimensions within which we want to draw inferences from our study program. At the same time, it is necessary to state the socioeconomic and legal contraints which dictate these limits. Once this is done, the project team can confine its attention within these carefully defined limits and avoid wasting its resources on areas and topics that are peripheral to its primary concerns.

Compile and Organize the Information Base

The study itself begins with compiling and organizing a base of existing information about the proposed activity and how it relates to the socioenvironmental systems under scrutiny. This compilation will occur from two principle sources (1) details of the planned development activities and possible environmental perturbations associated with each and (2) the best available information about the biological environment within which the activities will occur. The purpose of this compilation is to identify which of the stated information needs (objectives) is already met by existing information and which are the gaps in information needing to be filled by the study program.

Evaluate Alternate Sites

On the basis of information compiled from the literature, local experts and site surveys, now is the time to evaluate siting alternatives. The information for each site needs to be organized to permit easy contrasts between sites.

Identify Key Perturbations, Components, and Processes.

Once the above steps have been completed, we have a firm basis for proceeding with the really difficult job of choosing what ought to be measured in the field or laboratory during the baseline study. This requires identification of functional ecosystem response units, components, processes and attributes that are important to study.

Identifying these things involves the use of modeling techniques. Although the modeling technique required is the construction of simple box-and-arrow diagrams, the approach is compatible with more sophisticated techniques which some investigators may wish to utilize.

The determination of which components, processes, and attributes are important is based on three primary considerations. First, importance may be determined by legal and socioeconomic requirements of the decisionmaking framework. Second, importance may be a function of the position of the component, process, or attribute in the structure and function of the ecosystem. Third, a component is a likely candidate for study if it is likely to be affected by development activities.

The manual provides a stepwise procedure through which the relatively few things it is "important" to measure for a specific project are sorted out from the many things it is "possible" to measure. First, the manual user identifies the development activities likely to be of concern by working a modifiable two dimensional matrix with major types of energy developments across the top and preoperational and operational activities associated with those developments listed along the side. The next step is to identify the actual perturbations of concern (unusual changes in an environmental system that result in detectible changes in a component or process of that system) by using a second matrix. This matrix lists the same development activities across the top and the various environmental perturbations that may result from the activities down the side. Items of potential concern are marked by x's in the body of the matrix and the reasons for the concern are carefully documented.

In parallel with these activities the ecological study designer identifies the ecologically important components and processes of local ecosystems. Components are identified through a series of steps including (1) specify structural levels of resolution wanted, (2) choose the total time frame and seasons within that time frame that are pertinent to the project, (3) identify ecological response units that may be expected to react fairly uniformly to a given perturbation, and (4) specify the ecosystem components of concern and the attributes of those components that are most amenable to measurement. Important processes are identified by a straightforward modeling process whereby the biologists translate their mental models (what they believe to be the key interactions of the biological systems of interest) onto paper in the form of box and arrow diagrams. The major steps in this process include selecting the flow currencies, and drawing the flow diagrams by specified procedures.

Integrate Components, Processes and Perturbations

Next the study designer integrates the information derived by the two parallel procedures above using a third matrix which lists the key perturbations across the top and important components and processes down the vertical axis. By use of a simple numerical ranking scheme the significance of likely effects by each perturbation on applicable components and processes is indicated. The reasons for each ranking are carefully documented in terms of the relative (1) magnitude of the perturbation, (2) magnitude of anticipated effects, (3) persistence of the effects, and (4) human or political values which may alter strictly biological judgments.

Develop the Final Conceptual Model

The Impact Matix is a convenient and concise way of showing where and "how seriously" man-caused perturbations may affect the ecosystem. However, the actual effects may be importantly influenced by biological feedback mechanisms and these need to be looked at more closely. Consequently, procedures have been developed for elaborating earlier conceptual models into two types of diagrams showing how the important feedback mechanisms work. From these diagrams it is possible to identify more clearly the attributes of ecosystem components that must be measured in the ecological baseline studies. Process Control Diagrams are used to focus on each process identified as important, the components involved, and the perturbations and feedbacks that affect them. Then a System Control Diagram is developed to show how the selected processes interact with one another through both material flows and information flows. By following the effects of perturbations from their initial point of impingement on the system it is possible to anticipate and trace secondary, tertiary and higher-order impacts. Thus the complex ecosystems in the development area are reduced to their most important elements and interactions as a basis for gathering enough information in the baseline study program to permit verifiable predictions of effects from the proposed development.

If all this seems like a lot of work to design a baseline study, it's because it is. But it's certainly less work than the engineers must do to plan the project, and the purpose of all this preparation is the same as the engineers' careful planning: to avoid irreparable and costly mistakes later on. System control diagrams and all the steps that precede them force the ecologist to look at the total ecosystem and its functional components carefully and systematically to determine the components and attributes that must be measured in the baseline study. If the process control diagrams have been constructed carefully, selecting attributes (characteristics of an ecosystem component or process like color, biomass, rate, etc.) to measure will follow naturally from two criteria: (1) the importance of that attribute and (2) state of the art limitations on measuring that attribute.

Select Applicable Methods

Once ecosystem components, processes, and attributes of interest in the decisionmaking framework are identified, it is necessary to choose methods for measuring appropriate parameters. Methods selection is tempered by the limitations of the state of the art, including accuracy, efficiency, cost-effectiveness, and the amenability of various methods to statistical

analysis. Stepwise procedures for applying these important constraints to the final design of ecological baseline studies are too extensive to be included here. However, a major effort has been expended so that (1) where appropriate sampling methods do exist, advice is provided which will enable the manual user to select the best available methods for his particular situation, or (2) where appropriate sampling methods do not exist promising avenues are suggested for experimental innovation and research wherein appropriate methods might be developed. In either case the objective is to help the user design an ecological baseline study that meets the needs of the decisionmakers by applying the best available investigative methods.

CONCLUDING REMARKS

The results of an ecological baseline study should describe the existing ecological conditions and trends in the potentially affected region, providing a reference baseline from which environmental scientists can:

1. Predict the effects of the proposed action and recommend alternatives;

2. Define appropriate mitigation measures; and

3. Design future programs to monitor the accuracy of predictions and the effectiveness of mitigation.

The implications of this are very clear. Basically such a study should take into account the fundamental structure, function, and interrelationships of an environmental system in such a way as to predict, within reason and the state of the art, the effects of a proposed action on that system. This implies gathering data and other information about that system and organizing, distilling, and integrating the facts in such a way that the decisionmakers and others influencing the decision process can understand the environmental ramifications of the proposed action.

We believe that the philosophy, strategy, and specific methods I have summarized are extremely powerful for doing this. The potential applications of these methods are widespread, and, under NEPA and the trend of general environmental concern it has spawned, we believe the eventual use of these or similar techniques is inevitable.

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Integrated Multi-Resource "In-Place" Inventories[1]

Norman S. Adams[2]

Abstract.--A multiple-resource inventory was designed, conducted, and utilized in the development of land classification for timber management planning on the Siuslaw National Forest. Inventoried resources include Soils, Water, Wildlife and Fisheries, Visual, and Timber. Transportation systems and recreation facilities data was re-evaluated with the above for integrating into a unique process of resource value analysis and decision-making. Results have been utilized additionally for preparation of Environmental Impact Statements and on-going Land Management Planning. Experience to date provides excellent illustration of improved efficiency and thoroughness derived from an interdisciplinary approach to planning and integration of inventory bases. Illustrated are: inventory designs and techniques; integration process for analysis/decisions; data base developments.

INTRODUCTION

Certainly, the National Forest System has, in recent years, come under increasing political cross-fire, caught between conservationists and timber industry; the wilderness buff and the logger; the preservationist and the socio-economist, etc. Similarly, legislation through the RRPA, NFMA, and NEPA have all introduced new emphasis on both quantitative and qualitative planning and execution. NEPA alone has caused immense allocation of manpower and budgets to accommodate the requirement for E.I.S's. But the cause is good, and the early results indicate a vastly improved basis for land allocation and management of resources. One of the biggest changes has occurred in Resource inventories. With this new legislative emphasis, design and execution alike, have been inovatively modernized to establish much-improved foundations for planning and allocation decisions.

Two concepts which have evolved and are now fairly common are the "in-place" and "integrated multi-resource" concepts. These concepts are not new, but more a matter of new recognition for the "flexibilities in perspective" they offer the planner, the decision maker, and the concerned public. Subsequent to planning and management decisions, these same "foundations" remain for project development and execution.

THE SIUSLAW SITUATION

The Siuslaw National Forest, located on the Oregon Coast Range, is one of the most productive and natural resource-rich forests in the National Forest system. Its' abundance of wildlife, anadromous fisheries, and water production reflects similarly the capacity to produce softwood timber. Timber growth has been measured at better than 2 MBF/Ac./Yr. in natural stands. Approximately 77% of the 557,000 Ac. CFL base is considered Site II and better, and on the remaining 23%, a site index of less than 130 is uncommon. Today, a recognized CFL land base of aproximately 560,000 acres produces an Annual Allowable Harvest of approximately 350 MMBF, based upon the 1965 Forest TM Plan.

The recently calculated potential yield for the forthcoming planning period is approximately 450 MMBF per year, assuming intensive management practices are fully implemented. But all this richness is not without management problems.

Soils, in general, are extremely susceptible to forces of erosion and exhibit a common tendency for headwall failure and rotational failure, from road construction and

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[1]Paper presented at SAF National Workshop, "Integrated Inventories of Renewable Natural Resources;" Tucson, Arizona, January 1978.

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clearcut harvest practices. When coupled with a coastal climate influence and annual precipitation levels of about 80 inches, severe damage can easily result. This soil erosion potential is not only a risk to continued productivity for future stands but also contributes to water quality degradation which threatens domestic uses and anadromous fishery habitat. Water Quality is mostly affected by turbidity levels, which leads to sedimentation and habitat destruction. Risks are extreme; preventive and mitigating measures essential; and management practices costly.

In addition, visual values and recreation opportunities are somewhat unique as exemplified by the Oregon Dunes NRA and Sea Lion Caves. The proximity to the Pacific Ocean and fairly mild year-round weather produces year-round recreational visits from both local and regional population centers. Summers draw visitors in high numbers from all corners of the nation. These resource values draw considerable attention and cannot be treated lightly.

RARE II, for example, has identified approximately 90,000 acres of defined Roadless Areas on the 625,000 acre Forest. These areas, while highly productive for timber, also offer somewhat unique wilderness opportunity. This question of land allocation introduces complex consideration requirements. In such a complexity of resource and land use values, inventory data and information is often the only sound basis for decisions, whether administrative, judicial, legislative, or public.

BACKGROUND HISTORY

In 1971, the concept of Interdisciplinary Team Planning was plodding along at the rate of a unit plan per 18 months and $200,000. But this was not a unique situation as most R-6 Forests were similarly troubled. Management direction at all levels was lacking; something was wanted, but few knew what that something was. Teams were frustrated; managers in dismay, and in a quandary; accomplishment was slow. With a new Forest-wide timber inventory forthcoming in 1973, opportunity knocked, the door opened, and entrance was made. The entrant--Integrated, multi-resource inventory, carrying a map of the Forest, and a banner reading "IN-PLACE." The realizations were obvious:

1. Inventory of the entire Land Base.

2. Inventory of Multi-Resources

3. Inventory identified by ground location, IN-PLACE"

4. Inventory at a flexible scale basis

5. Inventory to accommodate broad Land Use Planning as well as functional Resource Planning.

THE CONCLUSION

"Inventory the Forest resources first, then plan." Use the inventory base for perspective in establishing planning unit boundaries, as well as management direction within the boundaries.

A new course was charted. (1) Conduct a multi-resource inventory. (2) Use interdisciplinary specialists to develop and satisfy comparable quality standards for each functional resource area. (3) Integrate the inventories and the specialist skills to satisfy, first, Timber Management Planning goals; second, Land Management Planning goals; and third, other Functional Resource Planning goals. (Indicated order based on timeframe goals, not indication of values or importance.)

So in 1973, concurrent with the Forest's timber inventory, conducted on an "in-place basis," inventories of Soils, Streams, Wildlife and Fisheries Habitat, and Visual Resources commenced and were to occupy nearly 3 years of time.

Two common features were present i.e.,

1. Inventories were conducted and/or directed by one or more skilled resource specialists, e.g.

Soils - 2 - 4 Soil Scientists
Water - 1 - 3 Hydrologists
Wildlife Habitat - 1 - 2 Wildlife Biologists
Fisheries Habitat - 1 - 2 Fisheries Biologists
Visual - 1 - 2 Landscape Architects
Timber - 1 - 4 Foresters
Engineering - 1 - 3 Logging Engineers, Environmental Engineer, Civil Engineer.

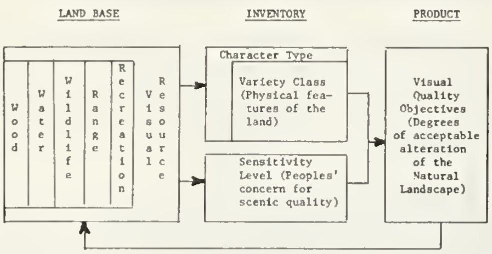
2. All inventories included mapping either originally conducted or later transferred to a common 2 inch = 1 mile topographic, quandrangle base maps. Mapping of riparian habitat and Streamside Management Units was not attempted because of the nature of these resource values and the immensity of the job.

INVENTORY DESCRIPTIONS

Visual Resources

This inventory was compiled on the basis of the service-wide National Forest Landscape

Management, Volumes 1 and 2. This inventory system has been applied throughout the National Forest system, and is a well-accepted, modern approach for land use and functional planning. The basic system can be described in the following manner:



Two features of the land are mapped and classified, i.e., (1) Variety Class, and (2) Sensitivity Level.

Variety Class.--Is identified as Class A-Distinctive, Class B-Common, and Class C-Minimal. The prevailing premise of Variety Classification is that all landscapes have an identifiable character, and that landscapes rich in variety have greater appeal than those less diverse.

Sensitivity Level.--Establishes a measure of peoples' concern for scenic quality and are determined for land areas viewed by people while:

1. Traveling on Forest roads and trails;
2. using Forest campgrounds and Visitor Centers;
3. recreating on lakes, streams, or other water bodies.

The prevailing premise here is that all National Forest land is seen, even if only from aircraft, therefore, all National Forest land can be classified for visitor sensitivity.

Three sensitivity levels are assigned, i.e.,

Level 1 -- Highest sensitivity (seen from major highways, orspecial interest area routes, designated recreation areas, waterbodies).

Level 2 -- Average sensitivity (see from Forest and County roads, other use areas, and water bodies not included in level 1).

Level 3 -- Lowest sensitivity (all seen areas not included in 1 and 2).

The combination of Variety Class and Sensitivity Level produce quality objectives in five categories, i.e.,

P - Preservation allows for ecological changes only.

R - Retention allows management activities which are not visually evident.

PR - Partial Retention allows management activities that remain visually subordinate to the predominantly characteristic landscape (in this case, the Oregon Coast Range characteristic).

M - Modification allows management activities that may dominate the natural characteristic landscape; that borrow from natural form, line, color, tecture.

MM - maximum Modification allows management activities that may dominate the natural characteristic landscape; only when viewed as a background.

The Visual Quality Objective Determination Matrix, illustrated below, summarizes the basics from which visual resources on National Forest lands are classified and introduced to Planning for decision-making.

VISUAL QUALITY OBJECTIVE DETERMINATION MATRIX

		Sensitivity Level						
		fg1	mg1	bg1	fg2	mg2	bg2	3
Variety Class	class A	R	R	R	PR	PR	PR	PR
	class B	R	PR	PR	PR	M	M	M MM
	class C	PR	PR	M	M	M	MM	MM

Legend

fg = foreground; mg = middleground; bg = background
R = Retention
PR = Partial Retention
M = Modification
MM = Maximum Modification

Figure 1.--Visual Resource Classification Matrix for Quality Objective Determination, USFS.

Soils

The soils resources are inventoried in the following manner:

1. The entire Forest was first mapped and classified by the R-6, Soils Resource Inventory (SRI) system. It provides basic soil, bedrock, and land form information for management interpretations and application of multiple-use principles. This inventory base produces two volumes in the report; one is a series of maps describing location and extent of the various soil types and characteristics; the second is a volume of tables and characteristics description for the identified types.

2. Subsequent to the SRI, the Forest land area was mapped and classified for <u>risk conditions for road construction</u>. Existing unroaded areas were delineated and evaluated against the SRI mapping to determine areas of unstable soils for future road construction considerations.

Four road construction--soils instability classes were mapped:

a. High risk from slumps.
b. Medium-high risk from slumps.
c. High risk from debris avalanches.
d. Medium-high risk from debris avalanches.

Soil mapping units from SRI were then identified into these <u>four</u> classes as illustrated below.

Siuslaw N.F.

Slump (Most Likely)				Debris Avalanches (Most Likely)				
Medium-High Risk			High Risk	Medium-High Risk				High Risk
7	261	542	421	21	154	251	512	31
43	452	543		34	185	412	552	47
52	521	546		42	225	424	554	54
151	525			44	231	442	561	80
252	541			51	241	511	651	447

This mapping was then evaluated from existing and projected road system locations against/with logging systems for both regeneration harvest and intermediate thinnings to establish limitations for timber management and harvest activities. It primarily establishes <u>a basis</u> for prediction of risk and management opportunities for long-range planning.

3. Again, subsequent to the SRI, soils were mapped for the entire Forest, to identify locations and extent of unstable soils <u>for future timber harvest by clearcutting systems</u>. <u>Two</u> risk conditions were independently mapped, i.e. (1) debris avalanches associated with timber harvest, and (2) slumps or rotational failures associated with timber harvest.

Debris Avalanches

Using aerial photographs, areas where such events have occurred were delineated and landform/soil characteristics recorded to establish typical characteristics. (This was on a sample basis.) This information was then extrapolated and applied to unmapped areas of similar landform/soil characteristics. Timing of the events in relation to timing of the clearcutting was determined important, as most such events occur within 1--10 years of the area denudation. Removal of trees and the subsequent channel disturbance, changes in root strength and soil moisture were determined to be the primary controlling factors in acceleration of debris avalanche landslides when roads and landings are not involved.

This mapping and inventoried information primarily establishes a basis for predictions of risk associated with timber harvest by clearcutting. Extremely sensitive areas can be better evaluated as a result, prior to implementation of projects. Long-range planning is extremely befitted as is project environmental analysis.

Slumps

The SRI, again, provided the primary basis for this mapping and inventory structure. From the identified high risk areas, a sample was conducted using aerial photos to establish recognizable features most commonly associated with the event. This information then extrapolated to unsampled high risk areas, for prediction purposes.

This sampling, coupled to the SRI mapping, and evaluated against a 1975 storm, is considered extremely reliable on the local basis. It provides a good basis for predictions associated with long-range planning, and establishes a "red flag" for environmental analysis in conjunction with timber management activities.

WILDLIFE INVENTORY

An extensive inventory was conducted to provide basic resource information, necessary in the development of long-range land use and functional plans, and the subsequent implementation.

The process included:

1. Literature review.
2. Researcher interviews
3. Field observations.

Wildlife information resulting included:

1. Abundance of species
2. Occurrence of species
3. Habitat requirements and trends
4. Status
5. Recreational use.

1. <u>Abundance</u> of each wildlife species, was approximated using a quantitative index, to ascertain the following levels of abundance:

a. very common
b. common
c. rare
d. irregular
e. present.

Approximations are considered general because of natural-occurring annual, seasonal,

and/or geographical variations in species abundance. The level of abundance described for each species is relative to its position in the ecosystem.

2. Occurrence of each wildlife species was described as frequency of residence on the Forest, in the following categories:

a. Resident, found year-round.
b. Summer Resident, breeds on Forest
c. Winter visitor,
d. Migrant, uses Forest during spring and fall
e. Unknown, use unknown
f. Summer Visitor, does not breed on Forest.

3. Habitat Requirements. Changes in habitat were observed and predicted. Comparisons between naturally-formed stand and man-created stands were made.

4. Habitat and species status were categorized as:

a. unaffected
b. benefited
c. adversely affected

by current and foreseeable changes from land/timber management activities and recreation use.

Examination revealed types of habitat which will be diminished or significantly altered on the Forest. These area-habitats were mapped for prediction and planning purposes.

The wildlife inventory, even though somewhat extensive has presented a never-before-available information source. It has vastly increased the perspective for all aspects of planning and project implementation. "Awareness of wildlife" among Forest personnel has been substantially enhanced, enabling greater objectivity in planning and execution of programs.

STREAMSIDE MANAGEMENT UNIT INVENTORY (SMU's)

This inventory reflects "stream influence and protection zones" and provides information pertinent to management planning of water, fisheries habitat, riparian habitat, and timber resources occurring within this zone. The foremost goal of the SMU concept is to meet State water quality standards, and maintain fish habitat. This goal is attainable through prevention of accelerated damage resulting from:

1. Loss of shading effects for temperature maintenance.
2. Organic debris accumulation.
3. Surface soil erosion.
4. Hydraulic channel scouring.
5. Post-debris torrent erosion.
6. Not attached here, but contributing, is prevention of landslides, discussed under soils.

It basically encompasses a classification system for all Forest streams. Four classifications are recognized:

1. Class I Streams. Those which are (a) direct domestic water sources; (b) high-value fish streams; and (c) normally flowing adequate quantities of water to influence water quality of other Class I streams.

2. Class II Streams. Those which are (a) medium-value fish streams, and/or (b) flow adequate quantities of water to moderately influence water quality of a Class I stream(s), and/or highly influence water quality of other Class II stream(s).

3. Class III Streams. Those which are perennial in flow, but not meeting criteria of higher class streams.

4. Class IV Streams. Those which are intermittent in flow, and do not meet criteria of higher class streams.

The process applied is illustrated below:

a. Map and classify Forest streams
b. Sample each stream class for:
   (1) distance totals;
   (2) landform, watercourse relationship, i.e.
      (a) stream class
      (b) drainage area
      (c) stream gradient
      (d) surface-soil-erosion potential
      (e) adjacent slope percentage
      (f) landslide hazard upstream.

SMU's have not been mapped and identified in-place. To do so would require field reconnaissance of approximately 9,300 miles of streamcourses. The magnitude of such a project is self-limiting. The sample system applied appears quite adequate for immediate long-range planning needs. It is not, however, replacing site or project specific examination prior to execution of projects.

TIMBER INVENTORY

The timber inventory was conducted on the regular R-6 schedule of Forest Survey. Advance developmental efforts allowed execution of the first R-6 in-place timber survey on a National Forest. Patterned from concepts developed in "The Siuslaw Model," four separate but inter-dependent phases were followed, i.e.

1. Stand mapping and classification phase.
2. Field inventory, plot phase.
3. Stand exam phase, for silvicultural opportunity.
4. Data base input and coordination phase.

1. Stand Mapping occurred in two steps:

a. Delineation on photo overlays, identifying boundaries of similar appearance, i.e., species composition, size, density based upon photo images of color, tint and shade, texture, and textural patterns.

b. Classification of delineated stands. The classifications appeared as alpha-numeric symbols with a single dash (-) where applicable. The alpha symbols identified species/groups based on silvicultural opportunities, i.e.,

A Hardwoods of pure or nearly pure compositions; based on crown cover 95--100% of spcies are hardwood.

CM Mixed conifer--hardwood; based on crown cover, conifers occupy 50--90% of the stocking, primarily mixed species (western hemlock, Sitka spruce, western redcedar, Douglas-fir).

DM Mixed conifer--hardwood; based on crown cover, conifers occupy 50--90% of the stocking. Conifer component is 70--100% Douglas-fir.

C Nearly pure conifer; conifers of mixed composition occupy 90--100% of stocking.

D Nearly pure Douglas-fir; Douglas-fir compositions occupy 70--100% of stocking ; total conifer is 90--100%.

Numeric symbols indicated size class, i.e.

Symbol	Diameter Range	Description
2	5-9"	Generally of unmerchantable size/age
3	10-29"	Generally normal range of comm. thin size/age.
4	30" +	Generally beyond normal thinning age.

A dash (-) symbol was used to indicate density levels of either adequate or inadequate. The dash (-) indicate stocking below minimum acceptable.

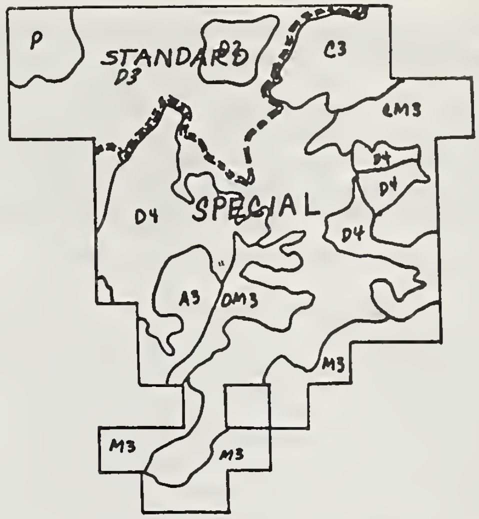


Figure 2.--Example of Timber Stand Mapping, Siuslaw N.F.

2. Field Inventory--Plots

a. The plot phase involved installations of some 571 variable point (10-point) plots on commercial Forest land. The 10 prism-points were adjusted to keep all points inside a stand boundary to increase sample reliability.

b. Mortality data was recorded on the first prism point, which was the point center for the first 1/5 acre subplot in the previous inventory.

c. Growth data was recorded from increment borings of trees on the first 3 prism points.

d. Tree measurement data, i.e. stump diameters, tree bole length, lenght--diameter relationships, and utilized log lengths was collected from approximately 500 felled trees on active sales.

e. Twelve percent of the established plots were inspected to insure maintenance of quality standards.

3. Stand Examination Phase.

A stand examination was conducted on each stand where an inventory plot was established. This project examined approximately 100,000 acres (slightly under 20% of the CFL), and provided the basis for silvicultural prescription assignment to inventory plots.

4. Data Base Input and Coordination.

The in-place stand maps were transferred to the Forest resource information system base maps for stratification and area determination. Stand exam data and plot data was incorporated

for Ranger District utilization, and Forest Timber Management Planning efforts.

Further, developments on-going, include adaptation of in-place mapping to WRIS computer system for automation of mapping base to be applied in further planning efforts and as part of the Timber Management Control System.

RESOURCE INVENTORY INTEGRATION PROCESS

With inventories completed, the process to integrate the resources mapping and information bases for various planning efforts was initiated. This process represents the key to integrated multi-resource planning and for functional Timber Management Planning. The process described here was utilized for the latter. A resource inventory, unto itself, at least for a National Forest, represents minimal multiple-use utility. It is the bringing together, the integration, of reasonably comparable inventory data and information for all existing resources that produces objective, multiple-use planning. Objectivity is further enhanced by interdisciplinary involvement, and commitment. The costs are high, but proportionally the payoffs overshadow the costs. Such has been the case for the Siuslaw National Forest. We 've previously described the people--interdisciplinary specialists involved--now let's turn our attention to what was done with the resource inventory bases.

Each non-timber resource mapped, classified, and measured, was distinguished in terms of "response units." These delineated areas represent existing conditions where similar responses to a given management activity can be expected, anywhere in the Forest. (In this instance, Timber Management Activities.) From the inventories discussed, nine basic response units resulted. They are: RU1--Visual Resources with Retention and Partial Retention quality objectives; RU2--Soils and Road Construction Risks; RU3--Soils--Debris Avalanche Risks; RU4--Soils, Slump, or Rotational Failure Risks; RU5--Older Forest Wildlife Habitat Risks; RU6 (unmapped)--Riparian Wildlife Habitat Risks; RU7 (unmapped)--Deciduous--Mixed Wildlife Habitat Risks; RU8 (unmapped)--Water/SMU Risks; RU9--Timber Stands without other resources Mapped.

When the individually mapped response units are overlayed, overlapping of response unit delineation occurs (see figure 3). This then creates multi-resource response units where for the same land area, two or more such non-timber resource risk conditions exist. Eighteen (18) such combinations of the Response Units 1, 2, 3, 4, and 5 were found to exist on the Siuslaw.

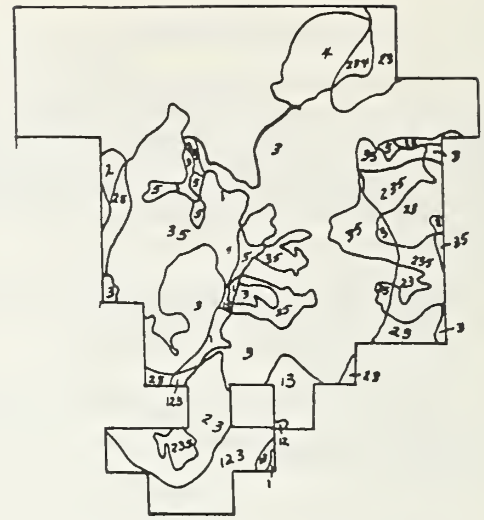


Figure 3.--Example of Response Unit Composite Mapping, Siuslaw N.F.

Because only Commercial Forest Land (CFL) was mapped over (in this case for a new Timber Management Plan) all individual, or combination response units overlap some form of timber stand, i.e., ranging from a recently cut-over clearcut to old growth stands. Approximately 270,000 acres of the total CFL was so mapped. In this instance, the mapped non-timber response unit acreage represented SPECIAL component lands for timber management planning. Breakdown by broad timber classes included approximately 1% hardwood; 37% mixed conifer and hardwood; 46% conifer; 16% plantations and recent cutover. A summary of the Forest's mapped response units is illustrated in Figure 4.

Recall the primary objective here was to accommodate the new TM plan. For each of the five mapped Response Units, five management options were developed by the interdisciplinary specialists. The options represented increasing--decreasing protection levels for the various response units; generally reflecting decreasing timber harvest and road construction to accommodate reduction in risk to the non-timber resource (see Figures 5 and 6).

From these options, the Forest Management Team, composed of Forest Supervisor and District Rangers, selected one single option for each Response Unit. (This selection was tempered by prior inputs from an external public working group and other Ranger District assistants.) The selected Reponse Unit options described acreages, and timber harvest, and road construction constraints which were to be applied to the TM planning effort. This represented the land allocation basis for that single planning effort. It represents an

update of the Forest Multiple-Use Plan, pending Land Use/Management Planning efforts/decisions which present publicly, alternative land allocations. Significant variation resulting from the public consideration of land allocations, will form the basis for subsequent TM Plan adjustments and a new Forest M-U Plan.

District	VISUAL	% of Total Dist. Acres	Soil Road Construction	% of Total Dist. Acres	Soil Debris Flow	% of Total Dist. Acres	Soil Rotational Failure	% of Total Dist. Acres	Wildlife Older Forest	Total District Acres
Hebo (1)	30,646	66.96	18,775	22.01	12,428	15.13	8,606	14.29	1,794	49,281
Mapleton (2)	22,270	17.91	45,201	36.35	85,104	68.43	1,129	0.91	2 17,912	121,154
Alsea (3)	12,955	28.13	15,355	33.34	14,812	32.16	7,778	16.89	6,550	43,629
Waldport (5)	16,449	27.82	27,731	47.49	16,977	28.80	11,526	19.76	5,128	56,672
FOREST	82,321	29.91	107,062	35.86	129,321	45.00	29,039	9.85	26,384	270,736

*Response Units 6, 7 and 8 are not mapped in place. In most cases, the areas are contained within another response unit, therefore, these acres are not additive to response units 1 through 5.

Figure 4.--Summary of Mapped, Non-timber Response Units, Siuslaw N.F.

Option	Description: Acres	Description: Visual Objective	Description: Distance Zone	Consequences to Visual Resource: % of Inventoried Visual Base	Consequences to Timber Resource: Acres	Consequences to Timber Resource: Yield %	Consequences to Timber Resource: Rotation Age	Secondary Benefits
I.	16,520	R	fg	176%	691	0	00	96 acres RU 3(1)
					15,829	69	200	133 acres RU 4(2)
	915	PR	fg		915	84	150	0 acres RU 5
	64,886	R	mg		64,886	87	150	126 acres RU 6
								350 acres RU 7(4)
								1,307 acres RU 8(3)
II.	16,520	R	fg	116%	691	0	00	96 acres RU 3
					15,829	69	200	133 acres RU 4
	915	PR	fg		915	84	150	0 acres RU 5
	13,312	R	mg		13,312	87	150	126 acres RU 6
	51,574	PR	mg		51,574	100	Normal*	350 acres RU 7
								1,307 acres RU 8
III.	5,551	R	fg	100%	691	0	00	96 acres RU 3
					4,860	69	200	133 acres RU 4
	12,061	PR	fg		12,061	84	150	0 acres RU 5
	6,788	R	mg		6,788	87	150	126 acres RU 6
	57,921	PR	mg		57,921	100	Normal*	350 acres RU 7
								366 acres RU 8
IV.	4,875	R	fg	86%	691	0	00	96 acres RU 3
					4,184	69	200	133 acres RU 4
	5,448	PR	fg		5,448	84	150	0 acres RU 5
	7,289	M	fg		7,289	100	Normal*	126 acres RU 6
	3,296	R	mg		3,296	87	150	350 acres RU 7
	61,413	PR	mg		61,413	100	Normal*	322 acres RU 8
V.	1,826	R	fg	82%	691	0	00	96 acres RU 3
					1,135	69	200	133 acres RU 4
	7,199	PR	fg		7,199	84	150	0 acres RU 5
	8,587	M	fg		8,587	100	Normal*	126 acres RU 6
	5,326	R	mg		3,296	87	150	350 acres RU 7
	60,718	PR	mg		60,718	100	Normal*	437 acres RU 8
	695	M	mg		695	100	Normal*	

Necessary Additional Management Input

Retention fg - 200 year rotation, group select for regeneration; hand site prep; large stock; close spacing; revegetation with non-crop ground cover. Retention and partial retention. fg & mg - small clearcuts; added site preparation costs; large stock; close spacing; mixed species; higher TSI costs; reveg with non-crop ground cover; logging costs will be higher than normal in all retention and partial retention due to unit size.

(1) $\frac{\text{Multiple RU1+RU3}}{\text{Total RU 3}} \times 691$ acres = RU1+RU3 secondary benefits.

(2) $\frac{\text{Multiple RU1+RU4}}{\text{Total RU4}} \times 691$ acres = RU1+RU4 secondary benefits.

(3) $\frac{\text{SMU protected acres}}{\text{CFL acres}} \times$ R fg = RU8.

(4) 50% of 691 acres R fg on 101 + Alsea Hwy will probably remain mixed.

KEY: R = Retention. PR = Partial Retention. M = Modification.
fg = Foreground. mg = Middleground. bg = Background.

* = Will not meet Visual Quality Objective 100% - due to clearcutting - not rotation age.

NOTE: Changes in sensitivity levels by management action are reflected in the Visual Quality Objective in each option.

Figure 5.--Illustration of Management Options for Response Unit 1, Visual Resources, Siuslaw N.F.

RESPONSE UNIT 8 - WATER
STREAMSIDE MANAGEMENT UNITS

Option	Description*	Consequences to Water Resource**	Consequences to Timber Resource	Secondary Benefits	Necessary Additional Management Input
I.	Class 1,2: LS(100) Class 3: LS (53) Class 4: LS (9), DP+R (38)	Class 1,2 = 99% overall protection. Class 3,4 - 1.8 times natural sediment discharge.	36,380 acres at 0% yield. 74,320 acres at 100% yield.	2,383 acres RU 1(1) 4,648 acres RU 3(2) 1,010 acres RU 4(3) 0 acres RU 5 12,576 acres RU 6 12,576 acres RU 7	Options I through IV call for revegetation of logged streamside strips. 47% of Class III's and 53% of Class IV's need no extra protection above normal contractural requirements.
II.	Class 1,2: LS(100) Class 3: LS (53) Class 4: LS (9), DF+R (19), DF (19)	Class 1,2 = 99% overall protection. Class 3,4 = 1.8 times natural sediment discharge.	36,380 acres at 0% yield. 74,320 acres at 100% yield.	2,383 acres RU 1 4,648 acres RU 3 1,010 acres RU 4 0 acres RU 5 12,576 acres RU 6 12,576 acres RU 7	
III.	Class 1,2: LS (50), PCLS (50) Class 3: PCLS (11), DF+NB (42) Class 4: DF+R (47)	Class 1,2 = 97% overall protection. Class 3,4 = 2.1 times natural sediment discharge.	8,050 acres at 0% yield. 10,220 acres at 50% yield. 92,430 acres at 100% yield.	2,383 acres RU 1 0 acres RU 3 0 acres RU 4 0 acres RU 5 5,224 acres RU 6 10,890 acres RU 7	
IV.	Class 1,2: PCLS (100) Class 3: DF+R (53) Class 4: DF (47)	Class 1,2 = 95% overall protection. Class 3,4 = 2.3 times natural sediment discharge.	16,170 acres at 50% yield. 94,530 acres at 100% yield.	2,383 acres RU 1 0 acres RU 3 0 acres RU 4 0 acres RU 5 0 acres RU 6 10,448 acres RU 7	
V.	Class 1: PCLS (60) DP+NB (40) Class 2: PCLS (6), DF+NB (94) Class 3: DP (53) Class 4: SC (47)	Class 1,2 = 93% overall protection. Class 3,4 = 3.5 times natural sediment discharge.	6,380 acres at 50% yield. 104,320 acres at 100% yield.	944 acres RU 1 0 acres RU 3 0 acres RU 4 0 acres RU 5 0 acres RU 6 4,532 acres RU 7	This option calls for stream cleanout, but no revegetation.

(1) $\frac{\text{RU 1 acres}}{\text{Reg. CPL acres}}$ x Class 1 + 2 protection acres. (2) $\frac{\text{RU 3 acres}}{\text{Reg CPL acres}}$ x Class 3 + 4 protection acres. (3) $\frac{\text{RU 4 acres}}{\text{Reg CFL acres}}$ x Class 3 + 4 protection acres.

*Numbers in parenthesis are % of total stream miles for the given prescription. LS = full, uncut leave strip; PCLS = partial cut leave strips, with 50% of merchantable timber removed; DF+R = directionally fill, burn, and artificially revegetate streamside strip; DF = directionally fill and burn; DF+NB = directionally fell and no burning in streamside strip; SC = stream cleanout after felling and yarding.

**Class 1,2: Overall on-site protection from on-site damage, compared to undisturbed forest (which is 100%). Class 3,4: Average annual sediment discharge for 5 years after cutting and burning, compared to undisturbed forest (which is 250 tons per square mile per year, according to Alsea Study).

Figure 6.--Illustration of Management Options for Response Unit 8, Streamside Management Units and Water Resources, Siuslaw N.F.

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A Comprehensive Inventory System for Forest Resource Management[1]

Gerald A. Rose[2]

The Michigan DNR has begun development of a multiple resource inventory system. Economic limitations have required development of flexible, segmented inventory systems which can eventually be combined. This system, built around a basic land unit inventory, also facilitates impact and trade-off analysis of multiple outputs under varying management strategies.

INTRODUCTION

Modern, progressive forest resource management requires an inventory and information system which not only provides information on individual forest resources, but one which permits analysis of management strategies to determine tradeoffs involved in alternative combination of resource outputs. Resource outputs from Michigan forest lands which have considerable significance in management policy and land use decisions are:

1. Wildlife: deer, ruffed grouse, sharptail grouse, turkeys, rabbits, elk, kirtland warblers, eagles, ospreys, and other song birds.

2. Developed Recreation: campgrounds, picnic areas, water access sites, pathways, and trails.

3. Dispersed Recreation: general use, hunting, fishing, berry picking, mushroom picking, and natural areas.

4. Timber Products: fiber and chip oriented or reconstituted wood products and lumber, veneer, and poles or solid wood products.

5. Water: clean water courses (stable flows and ground water recharge generally have less significance in Michigan except in highly developed areas).

6. Minerals: oil, gas, iron ore, copper, sand, gravel, and limestone.

Limited financial resources have forced the Michigan Department of Natural Resources to develop a cost effective inventory system which can be initiated in segments and over a period of time and yet one which provides critical linkages between segments to make the total system meet the impact analysis objective. In describing the total system we have envisioned, I want to emphasize that most of the ideas in the system are not new. You will recognize parts of systems developed and in use by others.

We have received much help from the U.S. Forest Service, both S&PF and the Region 9 staff in Milwaukee. We have also received much help from the staff of the School of Forestry at Michigan Technological University. Others have helped us, some of who I will mention as we talk about specific parts of the system.

BASIC LAND INVENTORY

The system is being developed around a basic land inventory. The Land Resource Programs Division within the Michigan DNR along with a progressive Regional Planning Commission are providing a major effort in the development of the basic land inventory.

Land base data of soil, surface geology, climate, water, vegetation, and wildlife is classified on a 10 acre grid cell basis.

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[1] Paper presented at the National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona, Jan. 8-12, 1978.

[2] Forest Resource Planning, Forest Management Division, Department of Natural Resources, Lansing, Michigan 48909

Examples of data classified are soil type, topography, aspect, land form, frost free days, annual precipitation, watershed, vegetative cover, and featured wildlife species or species group. This data is being classified and stored. Computer programs will be written to create similar response areas by considering certain specific classification combinations. An example of the combinations is shown in figure 1. Production co-efficients for each resource will be developed for each similar response area.

FIGURE 1

Example

SIMILAR RESPONSE AREAS - SRA

SRA 1 -	Soils:	Rubicon, Montcalm, and Graycalm
	Surface Geology:	Till Plains
	Vegetation:	Pines (predominantly Jack Pine), Aspen, Red Maple, Red Oak, White Birch, Sweet Fern, Blueberry
	Wildlife:	White tailed deer, sharptail grouse
	Climate:	Statewide zone 2
	Watershed:	Escanaba River (Lake Michigan)
SRA 2 -	Soils:	Rubicon, Montcalm, and Graycalm, and Kalkaska
	Surface Geology:	Morraines
	Vegetation:	Pines, Aspen, Birch, Spruce-Fir
	Wildlife:	White tailed Deer, Ruffed Grouse, Snowshoe Hares
	Climate:	Statewide Zone 3
	Watershed:	Manistee River (Lake Michigan)

SRA 3

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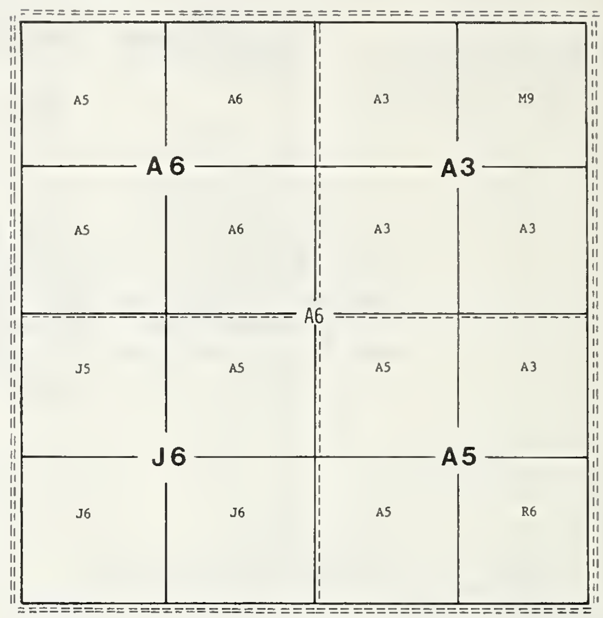
SRA 25?

Each classified 10 acre cell will also have available data on population, transportation, public service, etc., from information supplied by Regional and Local planning units. The joint nature of the system is important for both data collection and future use. Our experience has shown a willingness to cooperate on the part of most agencies who are concerned with land base data. All data in the basic land inventory can be displayed in map form. Aggregation of 10 acre cells into 40 and 160 acre cells for broader scale planning will be possible. The aggregation will be done by computer. (see illustration in figure 2)

FIGURE 2

Example - Aggregation From 10-->40 and 10-->160 Acre Cells



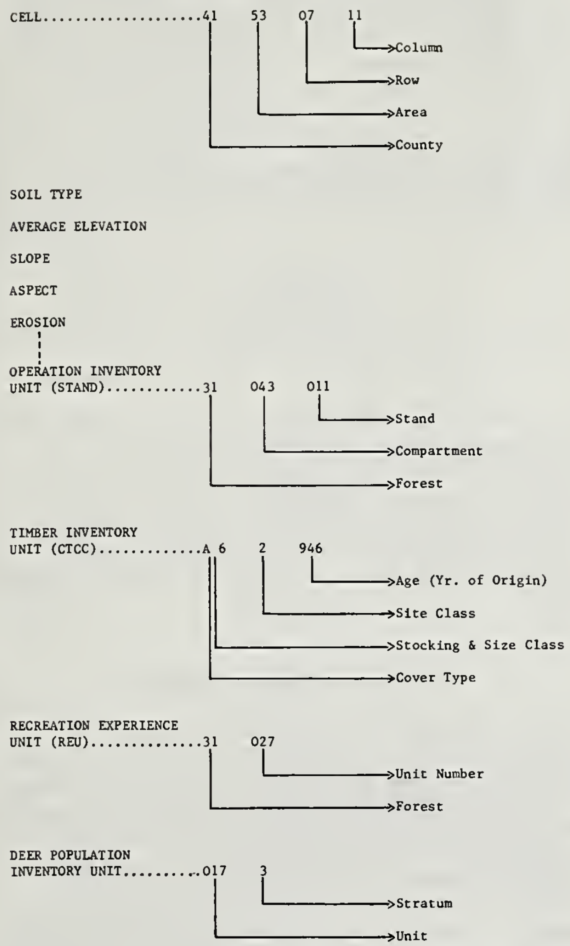
Classification - Vegetative Cover Type, Size and Density

The link between this basic land inventory, the operations inventory, and the individual resource inventories, will be accomplished by classifying the 10 acre cell by inventory unit for each of the other inventories. As an example, the operation inventory (which pertains to State Forest Land only) will be linked by coding the specific forest stand which predominates in the 10 acre cell. A cell coded 31043011 in the operations inventory unit field would identify the forest (31), compartment (043), and stand (011). As a result, all information available for stand 11 in the operations inventory file will be available for use in the basic land inventory file. Likewise, the unit for the deer populations inventory, recreation opportunities inventory, timber inventory, and any other resource inventory available will be coded and the data will be available for use in the grid file. (figure 3)

A very real benefit to having our operations and individual resources inventories linked to the basic land inventory is the potential availability of our data to regional and local governmental units for information and planning purposes.

FIGURE 3

BASIC LAND INVENTORY



OPERATIONS INVENTORY

Our operations inventory has been developed to provide information for tactical decisions in forest resource management-where we will cut, where we will create wildlife openings, etc. It is site specific with the basic unit being the forest stand. A minimum stand size of 10 acres has been established. However, stands in water, travel, and special zones and unique areas may be classified and recorded down to 2 acres in size.

Information recorded for each stand includes:

A. Stand area
B. Cover type-size-density
C. Site
D. Stand condition
E. Prescribed treatment
F. Treatment priority
G. Management objective type
H. Understory
I. Ground Cover
J. Basal Area (total, cut, TSI)
K. Four species-product combinations (by basal area and height to give timber, volumes)
L. Erosion hazard
M. Watershed treatment recommended
N. Special wildlife practices needed
O. Insect and disease problems
P. Special management area potential (which includes among other criteria the immediacy of development of adjacent areas).

Soil type will eventually be recorded for each stand, but will not be attempted for all stands immediately. Areas exhibiting greatest need for soil type information will be classified first.

Each stand is given a timber productivity classification of: timber producing forest land, timber producing forest land-reserved, non-timber producing forest land, non-timbered forest land, or water. Influence zone is also recorded with the usual general forest, water and travel and the following special zones:

a. Winter deer range
b. Other wildlife (specified on remarks card)
c. Recreation sites
d. Wild or natural areas
e. Undedicated
f. Developed by lease or long term agreement

Each stand is part of a compartment of 1,500 to 3,000 acres. Information is also recorded for each compartment. Along with the routine compartment information we record acres of wildlife openings needed, featured wildlife species, habitat condition for the featured species, recreation features (existing and potential), major year of entry (10-year interval), and entry interval. Each compartment will be assigned a planning unit number which will indicate the key value area or primary use designation. This classification will also provide a link to local governmental planning.(see figure 4)

FIGURE 4

COMPARTMENT PLANNING UNIT NUMBER

09 06

06 → Local Unit Designation

09 → Key Value Area

--A local unit designation may be recreation, prime timber, etc.

--Key value areas would be fiber, wildlife, quiet recreation, timber motorized recreation, etc.

Compartment and stand information is being computer processed with lists and tables made available to users. Lists available include stands scheduled for commercial sale, stands scheduled for non-commercial treatment, and non-commercial needs generated by sales. Timber volumes are summarized by compartment but due to the lightness of the sample are not summarized by forest or district. Other tables can be summarized by forest, district, region, and state.

Examples of tables produced are:

a. Area class by cover type
b. Area class by influence zone
c. Cover type by age class
d. Cover type by site class
e. Cover type by size class and stocking density
f. Cover type by ground cover

Each compartment which has had some type of treatment during a given year is updated by submission of updated information for the treated stands. A concentrated effort to get and maintain quality stand classification by cover, size density and site is a high priority. We feel this is our best opportunity to get the most reliable acreage figures by these condition classes. Also, annually these acreage figures will be current.

RECREATION OPPORTUNITIES INVENTORY

Very little developmental work has taken place on this inventory to date. In studying what has been done in the recreation opportunities inventory field we favor the approach taken in the Northern Region by the U. S. Forest Service in their publication Recreation Opportunity Inventory and Evaluation, June, 19 This approach calls for delineating recreation experience units (REU) and classifying each by:

a. attractive features
b. accessibilty and remoteness
c. visual resource characteristics
d. discord elements
e. visitation capacity elements

Using the information available from this inventory, we can identify and consider the key recreation attributes existing on state forest land. Our management for all resource outputs can be conducted in a manner which will either enhance the recreational opportunities or minimize the negative impact upon them.

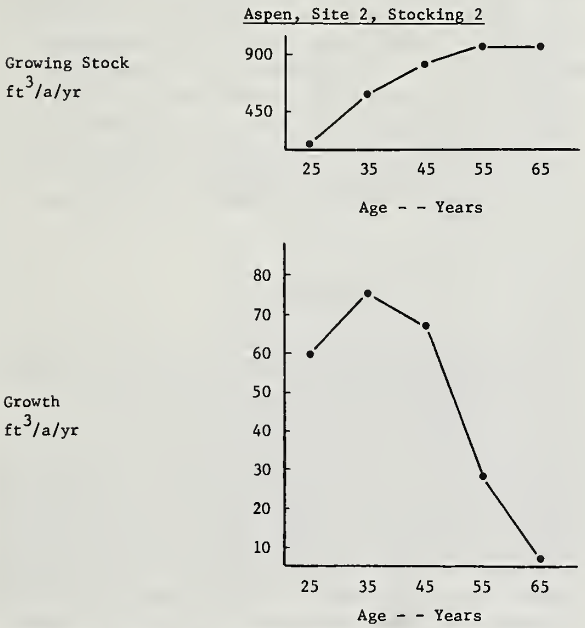
TIMBER PLANNING INVENTORY:

We recognize a continuing need for a periodic, light, statistically accurate timber inventory. When we began our operations inventory the feeling was that we could add together the volume figures for each stand and arrive at growing stock volume figures for larger areas. However, we were not long in finding out that it was an impractical approach. The largest problem we encountered was in statitistically analyzing our volume data. We would have to take too intensive a sample in each stand and thus slow down our operations inventory to the extent that it wouldn't be serving its intended purpose of directing desired management activities into the proper stands. In the past, we maintained a continuious Forest Inventory on each state forest (100,000-250,000 acres in size) establishing and remeasuring 8,000-1/5 acres permanent plots statewide. Because of our new objectives and approach to inventory, a modified procedure allowing fewer plots has become necessary. The objective of our timber planning inventory is to provide growing stock, growth, and mortality information by major cover type for a district or large state forest. The size of the inventory units range from 500,000 to 1,000,000 acres of state forest land. We plan to use a stratified douple sampling procedure, eventually building acceptably accurate growing stock and growth functions for each cover type condition class. In addition a species and product composition summary will

be made. The condition classes would contain the variables of site, stocking, and age in addition to cover type. Illustrations of these growing stock and growth functions are shown in (figures 5 and 6) for even-aged and uneven-aged management.

FIGURE 5

EVEN AGED EXAMPLE



For each cover type we would need nine displays similar to this one for aspen. This would apply to cover types managed on an even-aged basis. Our northern hardwoods being managed on an uneven-aged basis would require a different approach.

We cannot hope to achieve accuracy by each condition class immediately due to budget limitations. Therefore, the photoclassification phase of the double sampling procedure will give us a good comparison of the relationship of our sample to actual acreage figures developed in the operations inventory.

Our timber planning inventory will be on a 10-year periodic basis. We will build the accuracy of our sample in those condition classes which are considered important and are not adequately sampled. Also, in those condition classes which are adequatley sampled, we plan to drop down to a number of plots that would allow us to adequately monitor change.

Our acreage figures will come from our operations inventory—an annually current figure. Therefore, we can have an annually updated timber inventory. The importance of using consistent classification standards for both the timber planning and operations inventory becomes quite apparent.

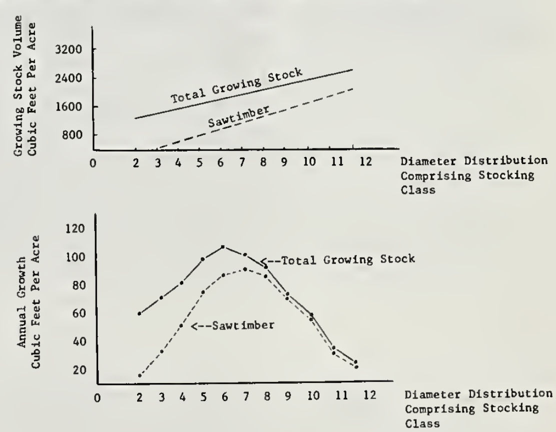
WILDLIFE POPULATIONS INVENTORY

We sample the population of many species of wildlife in Michigan just as is done in most states. Different procedures are used for different species. We have not worked with our Wildlife Division on an intensive basis yet to develop the links between the wildlife population inventories and the basic land inventory. However, we have had considerable wildlife input into inventory of habitat conditions which is accomplished in our operations inventory. Habitat for deer, for example, is summarized on a one quarter township basis. Guidelines for desired cover type composition and age class distribution are developed for the quarter township. The guidelines are used as a guide to prescription assignment in the operations inventory. Habitat condition for the featured wildlife species or species group will be coded in the basic land inventory.

The population inventory usually applies to a much larger unit. For instance, deer management units in Michigan are generally from 100-250 square miles in size. Several population censusing techniques are used including the pellet survey. In the pellet survey, the deer management unit is stratified into habitat types which are likely to have similar concentrations of deer. The deer population is inventoried annually. The link to the basic land inventory could be the deer management units and stratum. The population in deer per-square mile, 5 year average, trends, etc., would then be available for analysis against habitat.

FIGURE 6

UNEVENAGE EXAMPLE: NORTHERN HARDWOOD-SITE CLASS 1-STOCKING CLASS 3



Definition of
Stocking Classes

1 = 60-89 sq.ft/acre
2 = 90-119 sq.ft/acre
3 = 120+ sq.ft/acre

Definition of
Diameter Distribution
Comprising Stocking Class

2 = 30 sq.ft. sawtimber
3 = 30-39 sq.ft. sawtimber
4 = 40-49 sq.ft. sawtimber
'
'
12 = 120+ sq.ft. sawtimber

IMPACT ANALYSIS CAPABILITY

A major objective of our total forest resource inventory system is to provide capability to analyze management strategies to determine tradeoffs involved in alternative combination of resource outputs. We feel that we will have this capability with the total system described. The following chart shows the relationships of each component part of the system and the potential for analysis:

FILE A	FILE B
Basic Land Inventory	Operations Inventory Basic Unit- → Stand
Basic Unit-Similar Response Area (SRA)	
	FILE C
Coded Links— Stand Recreation Experience-Unit (REU) Cover Type Condition Class Deer Management Unit- and Stratum etc.	Recreation Opportunities Inventory- Basic Unit → REU
	FILE D
	Timber Planning-Inventory Basic Unit- → CTCC
	FILE E
	Deer Population Inventory Basic Unit → DMUS

In the system we've designed, we will have the capability of reaching into each file from the basic file. We can then display data from two or several files.

Production co-efficients will be developed by similar response area for each resource output. By applying the production co-efficient for each resource output under the management scheme considered, the level of each resource output can be determined using a multi-resource computer model for analysis. We are presently using the Goal Programming Model developed by Bartlett, Bottoms, and Pope (1976) at Colorado State University. We are using 237 decision variables to input our production coefficients and output levels under various management schemes. We also presently have identified twenty-eight resource output and budgetary goals with opportunity to vary the goal level for each. We find the use of the model to be fairly efficient in evaluating multiple outputs under different management strategies.

SUMMARY

As I mentioned in the introduction, we find ourselves with limited money and manpower to accomplish forest resource inventory. We need a system which can be initiated over time, and perhaps in part by other agencies, that will allow us to eventually reach our inventory objectives. In order to achieve this type of system, a basic framework is necessary so all resources can be analyzed and the information provided to our decision makers. The decision makers will then be able to allocate the forest resource to the production of a mix of outputs which meets the combined needs of all forest users.

We have a long way to go. As a matter of fact, we have just begun. However, we think we have a system that is workable with parts that are flexible and simple enough to be useable.

Current and Future Biomass and Resource Inventory Techniques[1]

Harold E. Young[2]

Theodore C. Tryon[3]

Clifford L. Swenson[4]

Abstract.--Completion of the first biomass-inventory of 63,251 acres of public lots in Maine in the spring of 1976 led to an immediate biomass inventory of 500,000 acres of private forest land in Maine. In 1976 a combined biomass-volume inventory of 1,8000,000 acres of forest land managed by Seven Islands Land Company in Maine began that includes pre-field reconnaissance, three weight tables for every tree and shrub species, a stand information retrieval system, biomass site productivity and participation of land owner foresters in the inventory process to maximize their use of the inventory when completed. Suggestions are presented by expanding biomass inventories to provide information for sophisticated forest management that will be both expected and required in the near future.

INTRODUCTION

Forest inventory is the process by which reliable and satisfactory information about the forest is obtained by sampling procedures. In general, the information collected should be all that is necessary for present and future management of the forest tract. Inasmuch as this workshop includes inventory specialists whose interests range from the broadest aspects of multiple resources to the narrow confines of a single segment of the forest, there could be a lengthy debate on how much information is necessary for forest management purposes.

For the past 100 years industrial forest management has been primarily concerned with raw material for conventional solid and reconstituted products. Now there is rapidly increasing interest in the forest potential (Young 1977) for solid and liquid fuels, food and fodder and basic materials for chemical industries. Much of this will come from presently unmerchantable species, forest residuals and mill residues, demonstrating that forest inventories limited to the merchantable bole of selected species are no longer adequate. Forest biomass inventories (Young, Hoar and Tryon 1976) including all tree and woody shrub species from the root

[1]Paper presented during National Workshop on Integrated Inventories of Renewable Natural Resources, Tucson, Arizona January 8-12, 1978

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tips to leaf or needle tips inclusive will provide complete vegetational information about the forest except for annual vegetation.

Experience has demonstrated that it may cost almost as much to revisit a set of sample plots for a small amount of additional information as it does to make the original set of plot measurements. This notion encourages exhaustive planning to minimize the likelihood of plot remeasurement. Biomass inventories can be made in concert with conventional volume inventories (Young, Hoar and Tryon 1976) (Hartranft 1975) at a relatively small increase in cost, primarily due to increased field time to measure small trees and shrubs on a subplot.

This paper will discuss modifications and improvements to previous inventories that with new ideas and concepts are incorporated in an inventory currently taking place on approximately 1,800,000 acres for Seven Islands Land Company in Maine. More improvements and modifications can be expected as more people become interested in this type of inventory and user experience is gained.

In a philosophic sense the authors believe that in order to obtain an adequate forest resource inventory, it should be all inclusive to insure sufficient information on hand to solve the myriad of problems that are constantly coming to the foreground as a result of our environmental awareness, the need for more forest products to meet the needs of society and the requirements of modern, effective and efficient forest management.

METHODS EMPLOYED

Pre-Field Reconnaissance.--Prior to photo interpretation and stand delineation, photo interpreters spend sufficient time randomly selecting and stereoscopically viewing aerial photographs so as to obtain sufficient familiarity with quality differences of the photo coverage of the area. Areas they deem necessary to check are noted and later visited.

Aerial Reconnaissance.--A recently modified recorder-survey technique which allows, through the use of fixed-wing aircraft, the ability to obtain, document and store stand description data along predetermined flight lines is used. Flying at low altitudes, two or three observers have the flexibility of simultaneously recording on a cassette recording device, descriptive comments relative to the area they are mapping. The flight lines are then plotted on the aerial photography with the documented observations being distributed along the flight lines by use of a timing device. These observations are tied into selected control points. This enables one to obtain substantial photo control data in a very short time.

Forest Stand Mapping.--The mapping employs current standard mapping procedures. Forest and non-forest detail, delineated on aerial photography, are transferred by use of conventional transferring equipment (Vertical Sketchmaster/Zoom Transferscope) to provide base sheets. A detailed series of appropriate checks yield completed stand maps, with all stands being sequentially numbered.

Field Work.--All trees from the 1.0" DBH class (0.61.5") and up are now included in the point sample. All trees and woody shrubs from one foot in height above ground to 0.5" DBH inclusive are measured on a 1/1000 acre plot. Points are selected on a random line basis. Lines generally run across topography and the number of points per line varies between 10 and 20. Desired accuracy is obtained with from 200 to 300 points per estimate unit. During the course of field work, stand mapping is corrected whenever possible from actual ground travel and measurements.

Weight Tables.--A series of field crews collected a considerable amount of biomass information on industrial tree species, non-industrial tree species and woody shrubs from 1963-1976 inclusive. In the fall of 1976 all of these data were used to prepare three regression equations, where appropriate, for the fresh weight of complete trees or shrubs as follows:

A) For Trees with DBH greater than 1.0" (1)

$$\text{Ln(Fresh Weight Complete Tree)} = b_o + b_1\text{Ln(DBH)}$$

B) For Trees and Woody Shrubs with DBH between 0.0 and 1.0" (2)

$$\text{Ln(Fresh Weight Complete Tree)} = b_o + b_1\text{Ln(DBH)}$$

C) For Trees and Woody Shrubs from 1.0 to 4.0 Feet in Height Above Ground (3)

$$\text{Ln(Fresh Weight Complete Tree)} = b_o + b_1\text{Ln(Height in Feet)}$$

In the first study, (Young, Hoar and Tryon 1976) a single regression equation representing the general average for all species was used. It was anticipated that minor species such as cedar would have high estimates and hardwood species such as the Maples and Birches would be too low, but that the overall average would be fairly good. The Public Lot data was rerun through the computer using the weight euqations now available. The overall results now are 2.6% higher and there were significant differences, as expected, for individual species. The new set of regression equations are now the best biomass equations available for Maine and some are still based on very limited data where there is insufficient data on hand to determine whether or not there are regional or site differences within the State. Conventional volume tables are used or applied to plot data to obtain product information in cords, M.Ft.B.M., and cunits.

Stand Information Retrieval.--For the designated inventory area each township and compartment within each township is coded. Each forest stand within a compartment is numbered and information on species, height, density, ground conditions, origin and history and acreage is recorded on the computer card. At present the information utilizes about one-half of one IBM card, however, the system does allow for more data storage to further describe and characterize the stand. Currently there is sufficient information on hand for forest management planning, operational planning and environmental studies by combining either volume or biomass estimates where appropriate. It is anticipated that additional information will be collected by field personnel so that with the passage of time stand information becomes more detailed and accurate, and therefore, more useful. The ultimate will occur when any question concerning the forest is raised and directed to the computer to obtain retrieval of a reliable estimate within a matter of minutes.

Site Productivity -- (Biomass in terms of weight as an indicator).--An incomplete biomass productivity study by the first named author has shown that the annual productivity of above ground stems and branches (wood and bark but without leaves or needles) for young hardwood stands is about 0.5 oven-dry tons per acre for wet and dry sites and about 1.1 oven-dry tons for meso sites. Young softwood stands have about 1.2 oven-dry tons per acre productivity in meso sites. Data on wet and dry softwood stands was collected in the summer of 1977 and will be analyzed.

Assuming that productivity on wet and dry softwood sites will be similar to that of wet and dry hardwood sites, it is possible to map productivity in three categories: wet, meso and dry. This alone can be of significant management importance because of the markedly different growth of the meso as compared to either wet or dry sites. It is anticipated that productivity mapping may be refined into as many as seven categories when much more biomass productivity data is available.

Site Productivity can be judiciously linked with logging methods by considering three categories of the latter: Conventional logging involving chainsaws and skidders; mechanical logging involving feller bunchers, skidders and mobile chipharvester; and unique situation requiring cables, balloons, helicopters, or some other special equipment. Supported by St. Regis Paper Company, a test has been made of about 10,000 acres. Site Productivity-logging designations were produced on overlays of the basic stand map by combining stand information, air photos and ground information. For stand retrieval purposes, it is essential that productivity-logging type boundaries coincide with type boundaries of individual stands or groups of stand boundaries. While provisions can be made for productivity-logging boundaries to cross stand boundaries, it is generally not practical, as this simply adds to the complexity of the inventory. Information provided by field foresters will make this part of the inventory more useful over time and in the long run, may turn out to be one of the most effective tools for overall forest management planning. To illustrate this, let us assume an ownership of 10,000 acres of forest land for which the owner is required to pay taxes on every acre. Site productivity logging condition mapping may show that for the present and foreseeable future, 6,000 acres can be opperated under normal conditions, 2,000 acres can be operated under only special conditions such as frozen ground and the remaining 2,000 can only be operated if unique harvesting equipment is developed. Such information should markedly affect not only operations such as harvesting, but will also influence the time and effort (money) spent for silvicultural practices, such as planting and thinning operations.

Land Owner Participation.--Either a highly specialized segment of the forestry department of a large land-owning company or consulting foresters usually conduct the forest inventory. The information obtained is then used primarily to prepare a management plan that is seldom used for day-to-day work in the forest. That is a harsh but not unfair comment on the limited use of forest inventory information by

many land owners. In sharp contrast, we advocate a philosophy of "living inventory", i.e., one in which the land owner, foresters and other personnel participate in the planning, field and mapping phases of the actual inventory. Of primary importance is the addition of information on almost a daily basis from field examination and continual use of the inventory information by making frequent requests via the computer for information on groups of stands for operation purposes, environmental studies, recreational studies, etc.

Land owner personnel who have had the opportunity to participate in the field work are more apt to want to use and have more confidence in the available information than those who did not participate. Therefore, land owner management will have to make a concerted effort to familiarize personnel with the inventory information and its availability. Once they become accustomed to the simplicity of called for information, the rapidity with which information comes back and the use to which they can put the information, than the guarantee of a "living inventory" will have been reached.

Participation by the Seven Islands Land Company foresters in the current inventory illustrates these concepts well. The Sewall Company is conducting the inventory in three segments conforming with the management districts. Prior to the inventory of a particular district, representatives of the consulting forestry company spent several days in the field with the land owner foresters to acquaint the latter with field methods of the inventory and to become familiar with marketing problems of the district. Then the land owner foresters spent a similar amount of time in the consultant's offices to become familiar with mapping and analytical methods and to provide information on the history of the land, roads, cut locations, etc. Such participation has already made the company foresters realize that (a) stand analysis time will be reduced to one-quarter for previous inventories, (b)information will now be available for state legal constraints and conditions such as the Maine Tree Growth Tax Law and (c) biomass information will permit more comprehensive five year planning particularly in view of potential customers interested in raw material for the production of energy, food and ofdder and basic materials for the chemical industries.

CONCLUSION

Whenever, in the future, a new inventory is required, a considerable mass of information will be on hand that will not have to be done over, as it is already in easily-accessed form to be incorporated immediately as the best available information. Stand boundaries will have changed due to harvesting and other events, but generally these can be maintained and simply up-dated. Field measurements appropriate to future needs should be made and utilized in both the volume and biomass inventories.

Each successive inventory or reassessment should bring about significant changes. For example, some soils information may be added between inventories, but a full soil survey of types related to tree growth might be incorporated in the second inventory. Between the second and third inventory information on animals, birds, and fish population might be partially included; but then become a regular feature of the third inventory. Again the concept of a "living inventory" means that information is constantly added aiming at total information in order to answer questions leading to more sophisticated forest management. These can be solved or investigated quickly by requesting the proper information from the computer file.

A brief outline and further comments to set forth the general concepts of this paper follows. Recent work appears to indicate that biomass in terms of weight relationships to site and D.B.H. have less variation than conventional volume relationships and hopefully as more information is gained, the use of biomass inventories will be maximized.

What are the limits of inventory? The answer lies in the limit to the sensible questions that might be asked and the imagination planning and execution of forest inventory by people with such inclinations.

A BRIEF OUTLINE OF COMPLETE FOREST MANAGEMENT

A. Productivity Sites

1.	Dry	Relatively homogenous units to be identified on airphotos and checked in the field. Supplemented continuously by field work.
2.	Meso	
3.	Wet	

B. Terrain Factors

1.	Steepness	Within the productivity unit terrain factors will influence type of harvesting equipment, frequency of Harvesting, etc.
2.	Boulders	
3.	Peat Depth	

C. Inventory Mapping

1. Forest type map separate - stand map and retrieval system.
2. Productivity site map separate to include:
   a. ridges
   b. streams
   c. regulatory restraints
   d. natural areas

D. Quantitative Inventory

1. Biomass and Volume (product) data for all woody species 1 foot and taller.

E. Growth

Site - Productivity in oven-dry tons per acre per year in wood and bark of branches and stems above ground.

Dry - 0.5	This is first estimate based
Meso - 1.0	on 101 biomass plots that
Wet - 0.5	were cut and weighed. Will be improved over time with more data.

F. Economic benefit from increased productivity through management and mix of products

1. Fertilizers	Example: If we increase
2. Planting	meso from 1.0 to 2.0 tons
3. Thinning	per acre per year, then
4. Genetics	the economic gain is more
5. Drainage	than the increased cost.
Etc.	

G. Planning for Site Units

1. Stocking
2. Productivity
3. Thinning Regime
4. Type of Products
5. Cutting Plans

H. Overall Plan for All Sites in a Lot or a Working Area such as a Compartment or a Township (requires some compromise with (G)

1. Road Construction
2. Protection - fire, insects and disease
3. Recreation
4. Forest Management

   a. Thinning and harvesting
   b. Planting
   c. Foliar analysis and fertilization

I. Utilization Integration

Cooperation and collaboration with all industries to insure maximum utilization consistent with second forest management.

J. Public Relations

1. General Public
2. State and Federal Agencies
3. University, Private Forest Industries, etc.

The intent is to develop a plan for today, for tommorrow and for the future. It can be considered as a model. Today possibly we would have no information in Compartment (F) and possibly in several other areas. However, we can plan in terms of the more simple model now that stand information retrieval and site information retrieval is both possible and practical. As we obtain more information we can make our model more sophisticated, not for the sake of sophistication, but in order to manage more efficiently and thereby bring in more profit to the land owner or manager. It has already been pointed out that such overall planning should insure that inventory is accomplished to meet all of the management objectives and this holds equally true for all other internal facets.

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A National Multiresource Inventory System: Possibilities, Problems, and Progress[1]

Robert C. Aldrich[2]

Abstract.--In response to RPA-1974, the Forest Service has taken a leading role in developing inventory techniques with assistance from other renewable resource agencies. Alternative approaches, problems, and progress related to multiresource inventory are presented and discussed.

INTRODUCTION

The need for periodic inventories of all renewable resources began 15 to 20 years ago but was brought to the critical point in 1974 by provisions of the Renewable Resource Planning Act (RPA).[3] The greatest force behind this was public pressure on resource managers to protect the environment while continuing to provide more services, goods, and recreational opportunities. The current emphasis on multiresource inventories, however, has several origins: (1) resource managers are frustrated with the nationwide forest resource base which deals only with timber; (2) growing public involvement in natural resources program decision making requires a greater variety of resource data, and (3) an increased interest in resource inventories is generated by research and development in inventory technology, including remote sensing, acute fuel shortages, and continual examination of relationships of current inventory procedures (Hughes 1974).

While there is no national multiresource inventory system, there is, however, a national continuing periodic timber inventory conducted by seven regional Renewable Resources Evaluation (RRE) Units.[4] Several of these RRE units collect other resource data. Generally, however, current timber and range resource inventory procedures and resource evaluation processes are fragmented within and among natural resource agencies. Because of this, aggregating multiresource data for national assessments such as called for in the RPA is difficult; its precision is questionable, and the data are inadequate to meet assessment and program planning requirements of the Act.

Although the RPA was the catalyst that brought requirements for multiresource inventory techniques to the forefront, the need for multiresource inventories goes beyond RPA. For example, multiresource inventories must respond to national, state, regional, and local resource assessment and land management planning needs, and they must also address questions about the quality of the environment

Multiresource Inventory: A Definition

The relatively new term multiresource inventory is undefined in the literature. Adjectives such as integrated, combined, and multipurpose are often used to mean multiresource inventory (i.e. the inventory of several resources at the same time). Our Research and Development program defines multiresource inventory as an inventory system in which sample measurements and observations of environmental attributes (i.e. vegetation, soil,

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[1] Paper presented at the Integrated Inventories of Renewable National Resources Workshop, Tucson, Ariz., Jan. 9-12, 1978.

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[3] Forest and Rangeland Renewable Resources Planning Act. Act of August 17, 1974 (88 Stat. 476; Sections 2 and 4).

[4] Renewable Resource Evaluation Units are organizationally under the Division of Forest Resources Economics Research, Forest Service, USDA. The units are authorized by provisions of the McSweeney-McNary Act of May 22, 1922 as amended by the Resources Planning Act of 1974.

water, climate, topography, and others) and existing information are analyzed to estimate current condition, predict potential, and assess resource use interactions. This approach to resources inventory is necessary because (1) it is much more economical than several independent single resource inventories, and (2) it allows measurements and observations of all required resource parameters to be made at the same time and at the same location, so that interactions between resources can be assessed.

Inventory Responsibilities

The RPA, as amended by the National Forest Management Act of 1976[5], recognize the necessity for long term planning and programs to meet the United States resource needs. The Act directs the Secretary of Agriculture to prepare a Renewable Resource Assessment not later than December 31, 1975 and update the Assessment by 1979 and every 10 years thereafter. The Act also amends the McSweeney-McNary Act of 1928[6] by directing the Secretary of Agriculture to make and keep current a comprehensive survey and analysis of the forest and rangelands of the United States, its territories and possessions, that will include their present and prospective condition and their supplies of and requirements for the renewable resources on these lands. The Act calls for cooperation with officials of the states, territories, and possessions of the United States and with private and other government agencies, it stresses the use of existing information when available. Authority to carry out the provisions in the Act was delegated to the Chief of the Forest Service.

Two other laws have a major impact on the development and conduct of multiresource inventories. The Federal Land Policy and Management Act of 1976[7], commonly known as the Bureau of Land Management (BLM) Organic Act, directs the Secretary of the Interior to prepare and maintain on a continuing basis an inventory of all public lands and their resources and other values. This inventory must be kept current to reflect changes in conditions and to identify new and emerging resource and other values. Finally, the Soil and Water Resources Conservation Act[8] directs the Secretary of Agriculture to carry out, through the Soil Conservation Service (SCS), a continuing appraisal of the U.S. soil, water and related resources. This appraisal would be made every 5 years and would include an analysis of the potential of those resources for various uses, and a determination of the changes in status and condition of those resources.

Problems associated with multiresource inventory are national in scope and touch upon both legislated and delegated authority of several federal agencies within more than one department. Although the Forest Service has been delegated the leadership role in RPA Assessments and Program Planning, the BLM and SCS have major responsibilities in multiresource inventories on the public lands and non-federal cropland and grazing lands respectively. Other departments and agencies that manage or oversee lands or resources, will also be involved. To avoid duplication, efforts are being made to coordinate inventory standards, terminology, and techniques among the agencies.

In 1975, the Forest Service established a Research and Development program at the Rocky Mountain Forest and Range Experiment Station in Fort Collins, Colo. to respond directly to RPA inventory and assessment requirements. The Resources Evaluation Technique Program (RET) has nationwide responsibility. Coordination with other Forest Service units and other federal and state agencies has already begun. For example, resource inventory specialists from both BLM and SCS are assigned to the program to assist in developing compatible resource inventory and evaluation techniques by taking a full part in the research program. Although the total RET goal is defined by five separate problems with interrelated concerns, one problem addresses inventory requirements and methodology. This problem, "to conceptualize the framework for a multiresource inventory system and develop the basis for an operational inventory for the timber and range resource components," will provide leadership to define information needs, define data elements required, develop procedures from existing or modified measurement techniques, evaluate inventory designs and procedures, and help to develop an automatic data processing system for display, storage, retrieval, and update of resource information. Although the most immediate need is for an operational timber and range inventory procedure by 1981, the longer term program goal is alternative

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[5] National Forest Management Act of 1976, Act of October 22, 1976 (90 Stat. 2949; Sections 3 and 6).

[6] McSweeney-McNary Act of 1928, Act of May 22, 1928 (45 Stat. 699, as amended; Section 9).

[7] The Federal Land Policy and Management Act of 1976, Act of October 21, 1976 (90 Stat. 2743; Sections 102, 201, and 202).

[8] The Soil and Water Resources Conservation Act of 1977 (This Act was not signed at the time of manuscript preparation but was expected to be signed before Jan. 1, 1978).

inventory procedures that will lead to a comprehensive multiresource assessment in 1989.

During the past year, the multiresource inventory problem was examined by a team of scientists with renewable resource, sampling statistics, inventory, and remote sensing backgrounds.[9] The analysis took a broad look at national resource inventory systems and multiresource inventory alternatives to define and break the problem into its components. From this analysis a research program was developed that hopefully will help solve the component problems.

INVENTORY ALTERNATIVES

To comply with provisions of the RPA, as amended by the National Forest Management Act of 1976, multiresource data must be collected, compiled, summarized, and analyzed for each state and an assessment made of present and future resources every 10 years. Currently, only the Nation's timber resource is inventoried on a continuing basis--the inventory cycle ranges from 8 to 10 years in the South to as long as 20 years in the West. In addition to shortening the cycle to 10 years for all areas of the Country, companion, compatible, or concurrent inventories must be made for range, wildlife and fish, recreation, and water resources. Data from these inventories must be provided in a way to allow assessment of resource use interactions. The inventory system must be both effective and economical and must integrate information from other sources, information collected using existing inventory techniques, and information collected using new techniques involving tools such as remote sensing, multiple purpose sampling designs, and computer technology.

Resource inventory and evaluation specialists have several alternatives for meeting RPA and other requirements. First, they can accept, extend, and use inventory design and measurement criteria they now use on all lands and integrate the inventory data in the best possible way. This means that information would be gathered from the best available sources, but would ignore the problem of incomplete and incompatible data. A second, and somewhat related possibility, would be to extend current national timber resource designs (Forest Survey) to all lands to provide compatible sampling designs for all vegetation. This would establish a common sampling design (with some regional variation in procedures). However, this rather simple approach would result in duplication of effort because other inventories would continue gathering similar data to meet the needs for intensification and finer resolution information.

A third possibility, would obtain supplementary resource information, using current forest and rangeland inventory designs, to satisfy the other resource requirements. This means that timber inventory procedures used by Renewable Resource Evaluation Units would be altered to measure herbage production on all lands that are classified as forest, and a national rangeland inventory design would be modified to measure timber on all lands classified as rangeland. Since the two technical land classifications will overlap in many areas, there would be duplication of effort and double accounting of some resources. Furthermore, forest and rangeland sampling designs are probably less effective and less efficient methods of estimating resources other than those for which they were developed.

We feel the best possibilities for a national multiresource inventory system are our fourth and fifth alternatives which follow two courses. One is to continue to use current Renewable Resource Evaluation inventory systems and permanent ground plots for timber (possibly with partial replacement) with a new and compatible sample layer for the range resource. The other is to modify current timber and range inventory designs to specify a single multiresource inventory system.

In the first alternative, the sample for range would be drawn based on range production variability (pounds per acre or some other parameter associated with herbage production) using known sources of information. Because herbage production is found on both productive and nonproductive forest land, the sample design would have to include herbage production on these lands and accommodate both sources of data. The last alternative would have flexibility at the regional level to meet local needs and would make maximum use of remote sensing. Some current timber and range inventory plots would be retained to remeasure vegetation and evaluate changes. While the initial cost of this alternative would be greater than the others, subsequent reinventories are likely to cost less.

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[9] Aldrich, Robert C., Richard E. Francis, Gary E. Dixon, Robert W. Dana, and Edwin H. Roberts, 1977. Problem Analysis: Conceptualize the framework for a multiresource inventory system and develop the basis for an operational inventory for the timber and range resource components. Resources Evaluation Techniques Program, Rocky Mountain Forest and Range Experiment Station, Forest Service, USDA, Inservice Report. Xerox 83 p and Appendices.

Because the first three alternatives for national multiresource inventories would probably be less effective for range and other nontimber resources, we decided that the most promising choice for research and development would be either alternatives four or five, or some variation or combination of the two. By taking these two approaches in our problem solution we feel that we have the best chance of meeting our goal (i.e., providing a framework for multiresource data collection by 1981). This approach provides flexibility to use different sampling designs and measurement procedures, remote sensing technology, and data analysis techniques to bring resource data together to satisfy information requirements. It also allows subsampling for resource parameters in a way most appropriate for each resource, either by phases or stages. Current national timber inventory procedures would be modified only slightly, thus retaining the capability to measure changes in volume, tree species composition and other attributes. In addition, values from forest and nonforest land would be aligned to a compatible data base.

THE PROBLEMS

The problem analysis has been completed and revised following reviews within the Forest Service and by BLM, SCS, and Fish and Wildlife Service (F & WS). Greatest difficulties were with semantics. This probably was a warning that our success will depend largely on how well we define information needs and data elements to address functional assessment requirements. Generally, there was agreement on the enormity of the task and the researchable components and studies we identified. The approach to the problem is flexible enough to be able to incorporate new findings, and change direction if future policy and program alterations require it.

Most multiresource inventory issues will fit one of four categories: (1) information requirements, or identifying and defining the resource and land parameters, (2) parameter measurement procedures, (3) inventory sampling designs and sampling procedures, and (4) data processing, storage, display, and data update systems. Following the planning steps taken in conducting an inventory, be it a single resource or multiresource inventory, we identified the issues and sorted them into the four categories, or component problem areas defined above.

Resource and Land Parameters

The most important part of the problem is the need to consolidate and develop a summary of multiresource inventory data requirements essential to all federal agencies either proposing or embarking on large-scale renewable resource inventories. Through this approach we can better identify and correct inventory deficiencies.

Before we can proceed with national, regional, and state multiresource inventories, however, we also need a national land and resource classification system. Commercial forest, noncommercial forest, barren land, rangeland, and other land classification systems must be redefined in terms of vegetation, soil, and other basic data elements in a hierarchical natural classification scheme, so that they can be measured but be mutually exclusive (or inclusive), combined, and treated analytically. This is important because there is an overlap between what is now classified as forest and what is classified as rangeland. Similarly, forest land, rangeland, and most other nonforest land could be classified as wildlife habitat.

A national land classification system is being developed by the Forest Service that will consider vegetation, soil, land form, and water, taking advantage of existing classification systems. Recommendations for a classification system will be submitted to the Chief of the Forest Service by January 1, 1978. The classification will be hierarchical, natural, and will accept technical classifications.

Timber and range resource parameters for natural assessments have been defined over the past 40 years. However, parameters for wildlife, water, and recreation for national assessments must be identified, so that these resource values can be quantified on land area unit samples. The wildlife and recreation parameters are being identified in separate studies identified in another problem in the RET Program. Water resource parameters will be defined in cooperation with the Water Resources Council. Although development of inventory techniques for timber and range will proceed at once, these techniques must be in concert with the other resources before recommendations are finalized.

Parameters associated with the present land condition must also be identified in terms of basic vegetation, soil, and water, so that what is present on the land can be measured or observed and management treatments recommended to improve growth and production if needed.

Measurement Procedures

Once land classes are properly defined, methods for delineating the area units can be developed to improve the information gathering

process. One method that shows great promise is remote sensing--whether it is conventional aerial photography or sophisticated multispectral scanner data. Remote sensing has the greatest short term potential for improving the measurement of the land area data base. Again, the greatest advantage will be realized if land classifications are made based on what is present on the land in terms of vegetation, soil, and water. Associated evidence can then be used to interpret the ecological potential or the landowner's intentions for using the land.

There is an emphasis on remote sensing research in our program because there are many problems that still must be solved before it can be applied in multiresource inventory. In recent years, LANDSAT data has become a continuing, economical source of low resolution (1.1-acre cells) information for land managers. LANDSAT data could give broad classifications and show changes in the land base by using temporal as well as seasonal data in computer aided classification systems. However, problems associated with cost effectiveness, registration of temporal data, use of ancillary information, geometric correction of data, and corrections for spectral variations due to slope, aspect, and elevation as well as sun altitude and angle must be resolved. We must also look at both conventional and unconventional photography to develop coefficients for estimating herbage production, species and species group cover, and nonvegetated ground surface.

National timber inventory ground measurement procedures are well developed using 10-point cluster samples. There are some regional variations of the 10-point cluster, but data are still both compatible and comparable and can be aggregated. Although range inventory ground measurement techniques are well developed, the application of these techniques vary within and between agencies, thereby causing problems in aggregating data for national, regional and state assessments. These techniques must be tested and alternatives recommended that will be compatible within and between agencies.

Some of the problems that influence the use, accuracy, precision and cost of range ground measurement techniques include: (1) how to evaluate trends over many years where inventory transects may be destroyed or moved, data lost, condition standards changed, and management objectives shifted, (2) how to remeasure range plots (the current inventory procedure) so that new data is comparable to data measured at the previous measurement, (3) how to measure the effects of trend causing factors (weather, insects, disease, etc.) that occur between measurements, and (4) how to effectively train range technicians to measure, remeasure, and interpert the data (Reppert and Francis 1973).

There are numerous other developments needed in range resource inventory including commonality or compatibility of terminology, measurement standards and techniques, methods for data collection for complicated ecological interpretations, and procedures to avoid measuring vegetation and other attributes on site-confounded sample locations. One major problem will be how to measure and analyze vegetation components on permanent sample sites during the same or different phenological periods of development. We also must develop adequate procedures for measuring soil characteristics that can be related to soil taxonomy and site productivity.

Sampling Design

Agencies now conducting resource inventories have no common procedure for the selection of sample locations. Various sampling designs are used within an agency, and inventories by different agencies are conducted independently. Consequently, the interrelationships between the resources become obscured. For example, timber inventories are conducted by seven RRE Units, and rangeland inventories are conducted through Forest Service Regions, SCS and BLM Offices. Wildlife inventories are conducted by state wildlife divisions and the Fish and Wildlife Service, USDI. However, timber production, range capabilities, and wildlife potential are not purposefully and strategically correlated for a given land area. The data collected for one resource is usually not compatible with data collected for other resources, which makes simple rational aggregation to national level statistics difficult.

Some standardization is necessary to attain a uniform multiresource data base and a system of collecting multiresource data to meet regional, state, and national information needs. Sampling designs and procedures will be reviewed and evaluated to recommend alternatives that will include the best of wildlife habitat sampling methodologies and include provisions for integrating other resource data.

There can be no single optimum sampling design for national multiresource inventories. The number of sampling designs is unimportant; however, they should provide data that is compatible. The sampling designs must deal efficiently and effectively with the populations to be estimated, selecting the sample size, selecting the appropriate sample unit size and shape, stratification, probability assignments, and estimating procedures. Without statistically effective and efficient sampling designs, efforts

in developing measurement procedures will be ineffective.

Data Processing, Storage, and Display

According to Ware and Hughes (1973), an information system consists of four parts: (1) data gathering, (2) data bank construction, (3) data or information retrieval, handling and update, and (4) various analysis subsystems to answer questions. The first of these is directly involved in developing a national inventory system. The remaining parts are directly or indirectly involved in the other four problems identified in the Resources Evaluation Techniques Program in Fort Collins. Since each part of the information system is dependent upon the others, there must be close coordination between the problem areas in the design, conduct, and analysis of the results of research studies.

Resource inventories must be certain that all basic data elements are collected, so that these data may be expanded to the acre, county, geographical unit, state, ecogroup, ownerships, and other aggregations, and estimates of precision can be computed to respond to multiresource assessment requirements. There is also a need to relate basic resource data to ancillary information from several sources; therefore it is important to identify all resource data collected by a common coordinate system such as the Universal Transverse Mercator (UTM) System. For this reason, techniques will be developed to identify coordinates in the most efficient and effective way possible.

PROGRESS

Although a large part of the first year was devoted to the problem analysis, there has been some noteworthy progress. Several studies are underway to resolve issues identified in this paper. Some of these accomplishments are identified briefly below:

1. A procedure has been developed for initiating an information needs assessment with input from Forest Service and cooperating agencies. The procedure will identify data collection requirements for the 1989 RPA Assessment and will be completed by January 1, 1979.
2. Range Management Divisions in Forest Service Regions have been solicited for latest range analysis procedures. These as well as procedures followed by SCS and BLM, are being evaluated for commonality and compatibility to answer national, state, and regional assessment needs. The most promising procedures will be tested in Grand County, Colorado and Kershaw County, South Carolina to develop alternatives for total vegetation inventory and analysis.
3. A cooperative multiresource inventory pilot study is being planned in Grand County, Colorado. The study will involve the Colorado State Forest Service and the Renewable Resource Inventory Unit at the Forest Service's Intermountain Forest and Range Experiment Station, Ogden, Utah. State-of-the-art timber and range resource measurement techniques will be used within an operational inventory framework on state, private, National Forest, and BLM lands. The inventory will identify problems in measuring and aggregating resource information. Primary photo grid points and secondary ground sample locations used in the inventory will serve as study sites for improving techniques.
4. An inventory design planning model was developed at the University of California, Berkeley, through a Cooperative Aid Agreement (Titus 1977). The model uses satellite and other data sources to create a population representation. Alternate sampling designs are evaluated to improve efficiency and effectiveness of securing data for resource inventories.
5. A study of Bayesian estimation methodology in forest sampling is being conducted at the University of Wisconsin. The study is designed to determine how Bayesian methodology could contribute to a national inventory system by improving precision of estimates of selected resource attributes with in-place data through multiphase or multistage sampling.
6. The potential sources of error in remote sensing data that must be accounted for to provide accurate results in resource inventories are being studied at Colorado State University (Heines and Smith 1977). The study investigates relationships of primary scene components (i.e., proportions of sunlit trees, sunlit understory, shadows, and rocks or bare ground) to spectral response in visible and near infrared regions at the spectrum.

There are 22 research studies identified in the Multiresource Inventory Problem Analysis that will be conducted in-house or by cooperators during the next 4 years. Again, our primary objective is to recommend compatible and cost effective alternative timber and range inventory procedures by 1981.

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Workshop Wrap-Up

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In the past few days, we have undertaken the formidable task of examining the possiblity of integrating the inventories of our natural resources. We have examined the information needs of our administrators and specialists, the past and present methods used to obtain this data, and the tools available for future efforts.

We have found that there is a sphere of information required for each discipline that includes vegetation and animals as well as the air, soil, water and minerals. The sphere varies in size with management needs, objectives and policy. We have also seen that there are areas of overlap between disciplines and needs were we might take advantage of combining our data collection efforts.

However, we have found that there are hidden problems with designing integrated systems. All disciplines, for example, may not need the data collected at the same time, at the same frequency, or at the same location on the earth.

Data may not need to be collected to the same degree of reliability for all disciplines. The intensity of the survey will vary according to the importance of the resource at the time the data is being collected. In addition all lands may not need to be inventoried for each and every resource.

In spite of these problems, we have seen that there is a need for some type of a combining of our inventory efforts. The primary reason for this is that the resources are interrelated and interdependent. By integration, we can provide a common base upon which managers can make more compatible decisions, and we can perhaps realize a savings in our inventory costs.

The design of an integrated system is not hopeless. The system will require coordination, planning and training. It will be more complex and require all the skills and tools available to be efficiently designed. The system must be flexible so that it can be bent, manipulated, or added to to meet changing management needs.

What will this future inventory system look like? That is difficult to say, but we can surmise that at a minimum it will have at least some of these following characteristics:

1. Be multidisciplinary in nature creating a hard core of basic resource data.
2. Be objective and credible.
3. Involve the need for standardization of terminology and perhaps standardization of measurement techniques between disciplines and between federal agencies.
4. Employ some form of land and/or vegetation classification scheme to define sample units. The formation and definition of these units may be as far as the "integration" effort goes.
5. Employ either automated or non-automated remote sensing systems to map these units.
6. Involve some form of stratified sampling to reduce cost and to provide timely information.
7. Our sample units, while reducing in number, will increase in size. Area sampling with related point sampling will become common.
8. Require automated data processing, information retrieval, modelling, and graphic systems to manipulate, play back, and update the information in a timely manner.
9. An initial inventory will form a nucleus from which more detailed discipline-oriented inventories may be launched. This provides a hierarchical foundation so that inventories for varying purposes can be interrelated with a minimum of collection and data processing effort.

Past inventories that have failed, have failed primarily because of poorly defined objectives and lack of communication between administrators, resource specialists and the inventory specialists. All are required. Excluding any one will spell defeat.

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To design the inventories of the future, we need to communicate. We need to communicate between disciplines and between agencies. This workshop and the proceedings have opened the doors for information exchange and hopefully have started us down the right path for designing objective, efficient and meaningful resource inventories.